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Measurement Techniques

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ACCURACY OF INDIRECT MEASUREMENTS INVOLVING MULTIPLICATION AND DISCRETE INTEGRATION

A. S. Nemirovskii and V. A. Volkonskii

Translated from Izmeritel'naya Tekhnika, No. 10, pp. 1-7, October, 1961

Quantities of gas or liquids are often measured by indirect methods which contain multiplying and integrating operations. For instance, when various flow components are determined in chemical production, the rate of the entire flow is measured, a quantitative analysis carried out, and the percentage content of a flow component determined. The product of these two quantities is integrated and then the required value is found. In determining the amount of heat, indirect methods are also used which contain multiplication and integration. The calorimeters contain flow and temperature measuring devices and a multiplying and integrating computer.

Thus, indirect measurements require two devices for determining the two factors, and a computer or a calculating machine for multiplying and integrating.

Often discrete measurements of one or both parameters are made and discrete integration carried out. The description of various multiplying and integrating computer circuits can be found in [1]. Errors in discrete integration and multiplication or discrete measurements of both parameters with subsequent integration are also dealt with in [1].

This article deals with errors inherent in indirect measurements by means of a multiplying and integrating circuit and due to a discrete evaluation of one of the parameters for the case when the measured values are stationary random functions of time.

For such measurements the value of the component for time T is calculated from the formula

$$Q=\sum_{j=0}^{n-1} y_{j\Delta}\int_{j\Delta}^{(j+1)\Delta} z_t\,dt, \tag{1}$$

whereas this component is actually equal to

$$Q_0=\int_0^T y_t z_t\,dt. \tag{2}$$

where z_t is the constantly measured parameter (for instance, the instantaneous rate of flow of a substance measured by a flowmeter); y_t is the discretely measured parameter (for instance, the percentage content of a component) at instant t; $t_j=j\Delta$ is the instant at which the $(j+1)$-th measurement of parameter y_t is made (i.e., when the value of $y_{tj}=y_{j\Delta}$ is measured); $\Delta=T/n$ is the measuring cycle (for instance, the time between two tests, between two consecutive measurements y_t).

It will be seen from (1) that in the cycle between the j and $(j+1)$th measurements the value of y_t is substituted by $y_{j\Delta}=y_{\Delta[t/\Delta]}$. Thus, $y_{\Delta[t/\Delta]}$ is a step function which is determined by the value of y_t at the instant of measurements, and $j=[t/\Delta]$ is the integer portion of quantity t/Δ.

It follows from (1) and (2) that the inherent error of the above indirect measurement is equal to

$$\delta Q=\int_0^T \left(y_{\Delta\left[\frac{t}{\Delta}\right]}-y_t\right) z_t\,dt. \tag{3}$$

The error δQ depends on the spectral characteristics of y_t and z_t (bandwidth and spectral density) and on time Δ (the quantization step adopted for y_t). Normally it is required to have only small variations of y_t during time Δ; however, such a requirement is too rigid and leads to the selection of small Δ and frequent measurements. A correct selection can only be made by studying the relation between δQ and Δ as well as the characteristics of the measured quantities.

Quantities y_t and z_t vary from measurement to measurement. For a stable technological process both these functions can be considered as stationary random processes, or as processes consisting of a stationary random part and a non-random function; however, in the latter case it should be assumed that the rate of variation of the non-random function is considerably smaller than that of the stationary process. With such an assumption it becomes possible to evaluate accurately only the stationary portions of the processes. Hence, let us consider y_t and z_t as stationary random processes.

It is known that a stationary random process always has a spectral expansion. Thus, it is possible to represent (3) in the form:

$$\delta Q = \int_0^T dt \int_{-\infty}^{\infty} d\eta_\lambda \int_{-\infty}^{\infty} \left(e^{i\lambda\left[\frac{t}{\Delta}\right]\Delta} - e^{i\lambda t}\right) e^{i\omega t}\, d\xi_\omega , \tag{4}$$

where λ and ω are the spectral frequencies of y_t and z_t respectively; η_λ and ξ_ω are the random spectra of the same processes.

The expectation value of the integration error is $M\delta Q = 0$. This follows directly from (3). The integration error dispersion $D\delta Q = M(\delta Q)^2$ can be obtained from (4) by calculating the expression under the integral:

$$\varphi(\lambda, \omega) = \int_0^T \left(e^{i\lambda\left[\frac{t}{\Delta}\right]\Delta} - e^{i\lambda t}\right) e^{i\omega t}\, dt = \tag{5}$$

$$\frac{(e^{i\omega\Delta}-1)\,[e^{i(\omega+\lambda)T}-1]}{i\omega\,[e^{i(\omega+\lambda)\Delta}-1]} - \frac{e^{i(\omega+\lambda)T}-1}{i(\omega+\lambda)} .$$

then

$$\delta Q = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \varphi(\omega, \lambda)\, d\eta_\lambda\, d\xi_\omega . \tag{5a}$$

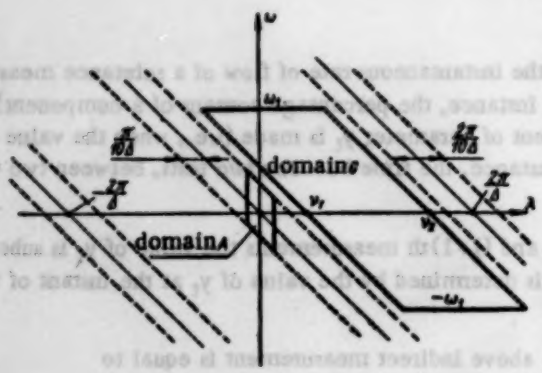

Fig. 1.

Taking advantage of the noncorrelation between spectral increments over stretches of frequency characteristics which do not cross and considering y_t and z_t to be independent, we obtain:

$$D\delta Q = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} |\varphi(\omega, \lambda)|^2\, d\Phi_\lambda\, dF_\omega , \tag{6}$$

where Φ_λ and F_ω are the spectral functions of y_t and z_t respectively

$$|\varphi|^2 = \Delta^2 \frac{1-\cos(\omega+\lambda)T}{1-\cos(\omega+\lambda)\Delta} \left| \frac{e^{i(\omega+\lambda)\Delta}-1}{(\omega+\lambda)\Delta} - \frac{e^{i\omega\Delta}-1}{\omega\Delta} \right|^2 \tag{7}$$

It is possible in fact to calculate the inherent error from (6) and (7). However, it is difficult to deduce from the

above formulas qualitative conclusions and to make the necessary computations without a further investigation of the results thus obtained.

Function $[\varphi(\lambda, \omega)]^2$ can be conveniently represented in the form:

$$|\varphi(\lambda, \omega)|^2 = \Delta^2 \psi(\lambda+\omega)\chi(\lambda+\omega, \omega), \tag{8}$$

where

$$\psi(\nu) = \frac{1-\cos T\nu}{1-\cos \Delta\nu}; \tag{9}$$

$$\chi(\nu, \omega) = \left(\frac{1-\cos \nu\Delta}{\nu\Delta} - \frac{1-\cos \omega\Delta}{\omega\Delta}\right)^2 + \left(\frac{\sin \nu\Delta}{\nu\Delta} - \frac{\sin \omega\Delta}{\omega\Delta}\right)^2 \tag{10}$$

(here $\lambda = \varphi + \lambda$).

Let us first examine the case when the number n of integration cycles Δ which occur over the whole integration time T is very large. Function $\psi(\nu)$ often fluctuates with respect to function $\chi(\nu, \omega)$, and over straight portions of $\nu = 2\pi k/\Delta$ (where k is an integer) function ψ assumes the value of n^2 (considering the $n = T/\Delta$ is an integer). These straight lines on plane (ω, λ) are shown in Fig.1. Away from these lines function ψ is small ($\psi \leq 2/1-\cos \nu\Delta$). Moreover, it can easily be verified that function $\chi(\nu, \omega)$ is limited over the whole of the plane

$$\chi(\nu, \omega) < 1{,}5. \tag{11}$$

It will be seen from equations (8), (9) and (10) the function $[\varphi]^2$ is especially large (of the order of T^2) when $\omega + \lambda = 0$, when ω is of the order of $1/\Delta$ or larger, and when $\omega + \lambda = 2\pi k/\Delta$. This can be illustrated by a simple example

$$\text{a) } y_t = \sin \lambda t, \quad z_t = \cos \omega t = \cos \lambda t \quad (\omega = -\lambda). \tag{11a}$$

These functions are represented in Fig.2. The step function is $y_{\Delta[t/\Delta]}$. It will be seen from the figure that over the portions where function y_t is increasing and the difference $y_{\Delta[t/\Delta]} - y_t$ is negative, function z_t becomes positive, and vice versa when $y_{\Delta[t/\Delta]} - y_t$ is positive, function z_t becomes negative. Hence, over the entire integrated portion from 0 to T function $[y_{\Delta[t/\Delta]} - y_t] z_t$ retains the same sign without any compensation. In this case the integration error is proportional to T.

$$y_t = \sin \frac{4\pi t}{\Delta}; \quad z_t = z = \text{const} \tag{11b}$$

$$\left(\omega = 0, \ \omega + \lambda = \frac{2\pi k}{\Delta}, \ k = 2\right).$$

Fig.3 shows process y_t, function $y_{\Delta[t/\Delta]} = 1$ (measurements are only made at instant $t = k\Delta$ when $y_t = 1$). In this case:

$$Q = z \int_0^T \left(1 - \sin \frac{4\pi}{\Delta} t\right) dt = zT \tag{11c}$$

(if T/Δ is an integer), i.e., it is also proportional to T.

For a more precise calculation of the error dispersion $D\delta Q$ it is necessary to calculate the value of the integral

$$I=\iint |\varphi(\omega,\lambda)|^2\,d\omega d\lambda \tag{12}$$

over various sections of the plane (ω, λ). It is convenient to calculate integrals over narrow strips of the type of*

$$\left|\omega+\lambda-\frac{2\pi k}{\Delta}\right|<0{,}1\frac{\pi}{\Delta} \tag{13}$$

separately from the strips where this inequality is not met. The fact is that it is impossible to provide an accurate expression for calculating these integrals (the integrals are not expressed in elementary functions). Therefore, the integral has to be evaluated for functions $\chi(\omega, \lambda)$ and $\phi(\omega, \lambda)$ by utilizing in the first case the smallness of $[\omega+\lambda-2k\pi/\Delta]$, and in the other case the slow variation of function $\cos T(\omega+\lambda)$ as compared with $\cos(\omega+\lambda)\Delta$.

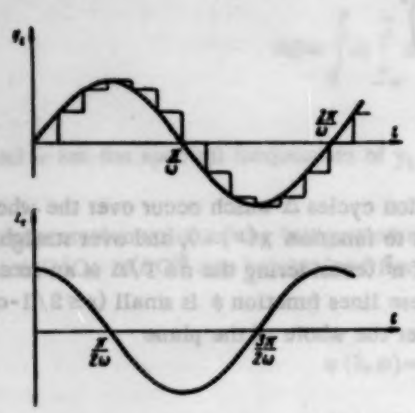

Fig. 2.

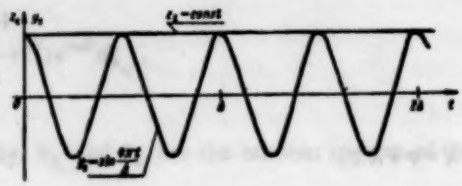

Fig. 3.

In order to find integral (12) by its middle strip

$$|\omega+\lambda|<\frac{\pi}{10\Delta} \text{ for } |\omega|<\omega_1 \tag{14}$$

(this corresponds to $k=0$) it is possible to write as a first approximation:

$$I\approx\Delta^2\int_{-\omega_1}^{\omega_1}\chi(0,\omega)\,d\omega\int_{-\frac{\pi}{10\Delta}}^{\frac{\pi}{10\Delta}}\frac{1-\cos T\nu}{\frac{1}{2}\Delta^2\nu^2}\,d\nu. \tag{15}$$

It is shown below that $\chi(\nu, \omega)$ approaches $\chi(0, \omega)$ when $[\nu]<\pi/10$. By integrating we obtain:

$$L=\Delta\int_{-\omega_1}^{\omega_1}\chi(0,\omega)\,d\omega=\frac{4}{\Delta\omega_1}\left(\cos\Delta\omega_1-1+\frac{\omega_1^2\Delta^2}{2}\right); \tag{16}$$

$$M=2\Delta\int_{-\frac{\pi}{10\Delta}}^{\frac{\pi}{10\Delta}}\frac{1-\cos T\nu}{\Delta^2\nu^2}\,d\nu=4\left[n\cdot Si\frac{\pi n}{10}-\frac{1-\cos\frac{\pi n}{10}}{\frac{\pi}{10}}\right], \tag{17}$$

where $Si\,x=\int_0^x\frac{\sin y}{y}dy$.

* A strip of this width has been chosen firstly because the number of measurements over the integration time is normally not less than 10, and secondly because for widths $> 0.2\pi/\Delta$ the use of the above approximations becomes excessively inaccurate.

This function (the integral sine) has been tabulated.

In obtaining the approximate formula (15) we have substituted function $[\tilde{\psi}]^2=\Delta^2\chi(\nu,\omega)\phi(\nu)$ by function $[\tilde{\psi}]^2=\Delta^2\chi(0,\omega)(1-\cos T\nu)/(\frac{1}{2}\Delta^2\nu^2)$. The error of this approximation can be evaluated in the following manner:

Function $f=(\Delta\nu)^2\cdot/([\psi]^2-[\tilde{\psi}]^2)/2(1-\cos T\nu)$ can be expanded in a series with respect to ν up to and including the term containing ν^2. Let us denote its approximate value by $\tilde{f}$. Then the greater part of the error of calculating I

$$\delta I=\iint(|\varphi|^2-|\tilde{\varphi}|^2)\,d\omega d\nu \tag{17a}$$

can be obtained from formula:

$$\delta I\approx\int_{-\frac{\pi}{10\Delta}}^{\frac{\pi}{10\Delta}}d\nu\int_{-\omega_1}^{\omega_1}\tilde{f}\,\frac{1-\cos T\nu}{\frac{1}{2}\Delta^2\nu^2}\,d\omega= \tag{18}$$

$$=\frac{1}{3}\left(\frac{\pi}{5}-\frac{2}{\pi}\sin\frac{\pi}{10}\right)\left[\frac{1}{\Delta\omega_1}\left(\cos\Delta\omega_1-1-\frac{(\Delta\omega_1)^2}{2}\right)+\right.$$

$$\left.+\frac{\Delta\omega_1}{4}-\frac{\Delta\omega_1-\sin\Delta\omega_1}{3}\right].$$

It will be seen from this expression that for small values of ω_1, which make expression (16) small, the value of (18) becomes negligibly small, and for the values of ω_1, which make the value of (16) appreciable, expression (18) becomes small as compared with (15).

Thus, the integral I (12) can be calculated approximately with respect to strip (14) from the formula

$$I\approx 16\left(n\cdot Si\frac{\pi n}{10}-\frac{1-\cos\frac{\pi n}{10}}{\frac{\pi}{10}}\right)\frac{1}{\Delta\omega_1}\left(\cos\Delta\omega_1-1+\right. \tag{19}$$

$$\left.+\frac{\Delta^2\omega_1^2}{2}\right).$$

It is possible to calculate in a similar manner integral I with respect to the narrow strip (13) for $k\neq 0$ and $[\omega]<\omega_1$.

In this instance

$$\Delta\int_{\omega_1}^{\omega_2}\chi\left(\frac{2k\pi}{\Delta},\omega\right)d\omega=2\left(Si\Delta\omega_2-Si\Delta\omega_1-\frac{1-\cos\Delta\omega_2}{\Delta\omega_2}+\right. \tag{20}$$

$$\left.+\frac{1-\cos\Delta\omega_1}{\Delta\omega_1}\right).$$

Integral I with respect to strip (13) is equal to the product of (20) and (17). In a manner similar to the case of $k=0$ it is possible to make the above formula more precise by including the next term of the expansion in the function under the integral.

Finally, let us evaluate integral (12) with respect to strip G (see Fig. 1).

$$\nu_1<\omega+\lambda<\nu_2 \text{ for } |\omega|<\omega_1, \tag{20a}$$

where

$$[2(k-1)+0,1]\frac{\pi}{\Delta}<\nu_1<\nu_2<[2k-0,1]\frac{\pi}{\Delta}.$$

Here it is possible to evaluate with sufficient accuracy by using the inequality (11).

Let us note that function cos Tz fluctuates in strip G at a higher rate than function $1/(1-\cos\Delta\nu)$.

Hence

$$I \ll 1{,}5\Delta^2 \iint_{O} \psi(\nu)\, d\omega d\lambda = 3\Delta\omega_1 \int_{\nu_1}^{\nu_2} \frac{1-\cos T\nu}{1-\cos \Delta\nu} \cdot \Delta d\nu \approx 3\lambda\omega_1 \int_{\nu_1\Delta}^{\nu_2\Delta} \frac{du}{1-\cos u} = 3\lambda\omega_1 \left(\operatorname{ctg} \frac{\nu_1\Delta}{2} - \operatorname{ctg} \frac{\nu_2\Delta}{2} \right) \tag{21}$$

This evaluation may be too high, since we have substituted function $\chi(\nu, \omega)$ by its maximum of 1.5. This is particularly important in the low-frequency range, since most of the power in the spectrum is concentrated in the majority of cases precisely in this range. Hence, integral I can be calculated more accurately from the formula

$$I = \iint_{O} \frac{\chi(\nu, \omega)}{1-\cos \Delta\nu} d\nu d\omega, \tag{21a}$$

by using Table 1 of the values of function χ.

If the spectra of y_t and z_t contain small frequencies only, the integration error must be small. In this case integral I (12) can be calculated by substituting function $[\psi]^2$ under the integral by the first term of its power series at point $\omega = 0$, $\lambda = 0$

$$|\varphi|^2 \approx \frac{\Delta^2}{2} \cdot \frac{1-\cos T\nu}{\Delta^2\nu^2} \lambda^2\Delta^2 \quad (\text{for } \nu = \omega + \lambda). \tag{21b}$$

Let us denote domain $\{[\nu] < \nu_1, [\lambda] < \lambda_1\}$ on plane (ω, λ) by A. Let us now evaluate the integral

$$I = \iint_{A} |\varphi|^2 \, d\lambda d\nu \approx \frac{2}{3} \Delta^2 \lambda_1^3 n \left(Si\, \nu_1 T - \frac{1-\cos \nu_1 T}{\nu_1 T} \right). \tag{21c}$$

TABLE 1.

$\omega\Delta$ \ $\nu\Delta$	0	$\frac{\pi}{12}$	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{5\pi}{12}$	$\frac{\pi}{2}$
0	0	0,017	0,067	0,15	0,258	0,39	0,536
$\frac{\pi}{12}$	0,017	0		0,067		0,251	
$\frac{\pi}{6}$	0,067		0		0,065		0,252
$\frac{\pi}{4}$	0,15	0,067		0		0,064	
$\frac{\pi}{3}$	0,258		0,065		0		0,062
$\frac{5\pi}{12}$	0,39	0,251		0,064		0	
$\frac{\pi}{2}$	0,536		0,252		0,062		0

If we assume that the common spectrum of processes z_t and y_t is contained entirely in domain A and has a constant density $f = DzDy/4\nu_1\lambda_1$, then

$$D\delta Q = fI \approx \frac{DzDy}{6} \cdot \frac{\Delta^2\lambda_1^2}{\nu_1} n \left(Si\, \nu_1 T - \frac{1-\cos \nu_1 T}{\nu_1 T} \right). \tag{21d}$$

This computation is only valid if frequencies ν_1 and λ_1 do not exceed the value of, say, $0.1\,\pi/\Delta$. On the other hand, the evaluation of the error dispersion with respect to the frequency of the processes is only interesting when the integration time T contains several oscillations of the measured process. We shall assume, therefore, that $T \geq 5\pi/\lambda_1 \geq 50\Delta$. With these assumptions $Si\, \nu_1 T - (1 - \cos \nu_1 T)/\nu_1 T \approx \pi/2$ and

$$D\delta Q \approx \frac{Dy_t\, Dz_t}{4} \cdot \frac{T\Delta^2\lambda_1^2}{\nu_1}. \tag{22}$$

Let $n = 50$, $\lambda_1 = \nu_1 = 0.1\,\pi/\Delta$ and $Dy_t = Dz_t$. The limiting referred integration error will then be:

$$\frac{(\delta Q)\lim}{T} = \frac{3}{T}\sqrt{D\delta Q} = 0{,}4Dz_t; \tag{22a}$$

if $Dz_t = 0{,}02$, then $\frac{(\delta Q)\lim}{T} = 0{,}8\%$.

Let us now show by an example how to calculate by means of the above data the inherent error δQ of a discrete multiplying and integrating circuit.

For these computations it is necessary to know the probability characteristics of the measured process. We calculated them for a flow considering that it consists of a stationary portion z_t with a zero expectation value and a non-random function m_t ($q_t = z_t + m_t$). Normal methods were used for computations (see [1] and [3]), i.e. m_t was selected by means of a mean curve, one application of the process was considered (assuming the process to be ergodic) and the following formulas

$$\left.\begin{aligned} Dz &= \frac{1}{n}\sum_{k=1}^{n} z_{k\Delta t}, \\ r_{s\Delta t} &= \frac{1}{(n-s)\,Dz}\sum_{k=1}^{n-s} z_{k\Delta t}\cdot z_{(k+s)\Delta t} \end{aligned}\right\} \qquad (23)$$

were used for calculating the dispersion D_z and the correlation function r_t.

The values of $r_{s\Delta t}$ for various values of s were calculated and plotted (Fig.4). They lie close to the curve

$$r_t = e^{-0{,}023t^2} = e^{-\frac{t^2}{2\cdot 4{,}65^2}} \quad (t \text{ in min}) \qquad (24)$$

The spectral density corresponding to this correlation function is

$$f_z(\omega) = \frac{4{,}65}{\sqrt{2\pi}}\, e^{-\frac{4{,}65^2\cdot\omega^2}{2}}. \qquad (24a)$$

Process y_t (for instance, the variation in the content of the measured component in the flow of the substance) varies slowly. We can consider that it has a uniform spectrum $f_y(\lambda) = 1/2\,\lambda_m$, where λ_m is the largest frequency in the spectrum. This corresponds to the correlation function $r_t = \sin\lambda_m t/\lambda_m t$, which decays almost completely for $\lambda_m t_0 = \pi$, for instance for $t_0 = 30$ min or $\lambda_m = \pi/30$.

Now we can formulate the data for our example.

Example. It is required to calculate the inherent error in measuring the value of a component contained in the substance flowing through a pipeline, if this error is due to discrete measurements of the percentage content of this component and if

a) the measuring time is $T = 1920$ min (24 hr);

b) the measuring cycle of the percentage content is $\Delta = 30$ min ($n = T/\Delta = 48$);

c) The normalized (i.e., $\int_{-\infty}^{\infty} f_z\, d\omega = 1$) spectral density of the flow is:

$$f_z = 1{,}85\, e^{-10{,}8\omega^2} = 1{,}85\, e^{-\frac{1}{2}\left(\frac{\omega}{0{,}216}\right)^2}; \qquad (25)$$

d) the normalized spectral density of the percentage content is

$$f_y = \begin{cases} \dfrac{30}{2\pi} = \dfrac{\Delta}{2\pi} & \text{for } |\lambda| < \dfrac{\pi}{\Delta}; \\ 0 & \text{for } |\lambda| > \dfrac{\pi}{\Delta}; \end{cases} \qquad (25a)$$

e) the flow dispersion is $D_z = 0.04\, z^2_{max}$ (the rate of flow varies over the whole range at a normal distribution law and the range lies in the field of $\pm 2.5\sigma$);

f) the percentage content dispersion is $Dy = 0.0004\, y^2_{max}$ (varying in the range of $\pm 10\%$).

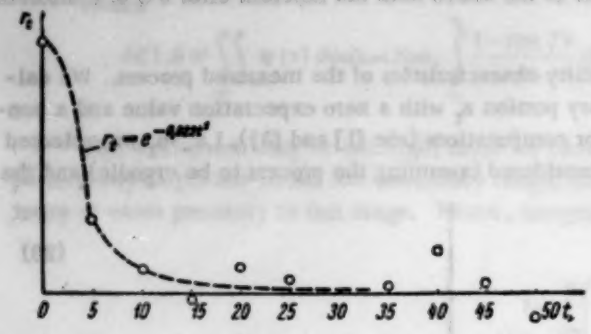

Fig. 4.

TABLE 2.

Domain designation	A_1; A_1—1	B_1; B_1—2	A_2; A_2—2	B_2; B_2—3	A_3; A_3—3	B_3; B_3—4	A_4; A_4—4	B_4; B_4—5
max	0	$1{,}1\frac{\pi}{\Delta}$	$2{,}9\frac{\pi}{\Delta}$	$3{,}1\frac{\pi}{\Delta}$	$4{,}9\frac{\pi}{\Delta}$	$5{,}1\frac{\pi}{\Delta}$	$6{,}9\frac{\pi}{\Delta}$	$7{,}1\frac{\pi}{\Delta}$
max	1,85	1,6	0,69	0,6	0,11	0,088	0,0069	0,0048

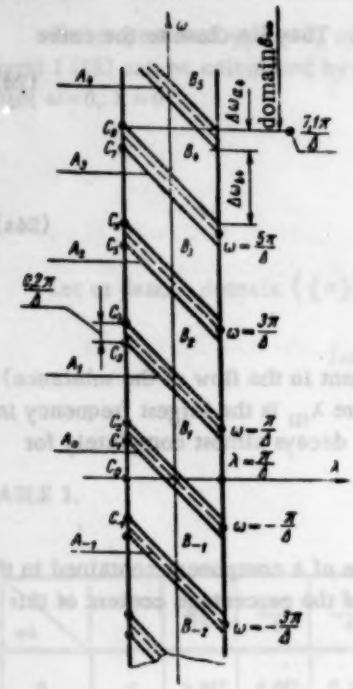

Fig.5.

Fig.5 was used for computations. The whole spectrum lies between vertical lines $\lambda = \pi/\Delta$ and $\lambda = \pi/\Delta$. Let us divide the whole domain into narrow strips A_0, A_1, A_{-1}, A_2, A_{-2} A_3, A_{-3}, A_4, A_{-4}; wide strips B_1, B_{-1}, B_2, B_{-2}, B_3, B_{-3}, B_4, B_{-4}, B_5, B_{-5} and domains B_∞ and $B_{-\infty}$ which lie above strip A_3 and below strip A_{-3}.

The error dispersion δQ which is determined from (6) may be represented in the form

$$D\delta Q = \sum \left[\int_{A_i} |\varphi|^2 \, d\Phi_\lambda \, dF_\omega + \int_{B_i} |\varphi|^2 \, d\Phi_\lambda \, dF_\omega \right]. \tag{26}$$

This formula may be used if the whole frequency domain is divided into small domains, and for each the value of

$$\left(\frac{d\Phi}{d\lambda}\right)_k = f_{yk} \cdot D_y; \quad \left(\frac{dF}{d\omega}\right)_k = f_{zk} \cdot Dz \tag{26a}$$

is computed (since f_y and f_z are the normal spectral densities). It is possible to take for f_{yk} and f_{zk} their maximum values inside the domain and obtain

$$\frac{D\delta Q}{Dy \cdot Dz} < \sum \left[f_{yi} \cdot f_{zi} \int_{A_i} |\varphi|^2 \, d\lambda \, d\omega + f_{yj} \, f_{zj} \int_{B_j} |\varphi|^2 \, d\lambda d\omega \right]. \tag{27}$$

In calculating integral $[\psi]^2 \, d\lambda d\omega$ as a sum of domains A_i we can use expressions (16),(17), and (20).

Then for strip $A_0 [\omega] \leq \pi/\Delta$; $\omega_1 = \pi/\Delta$

$$L_{a0} = \frac{4}{\pi}\left(\cos\pi - 1 + \frac{\pi^2}{2}\right) = 3{,}72; \tag{27a}$$

$$M_{a0} = 4\left(48 Si\, 4{,}8\pi - \frac{1-\cos 4{,}8\pi}{0{,}1\pi}\right) = 333.$$

Since the value of M_a is the same for all the narrow domains, it is only necessary for the remaining strips to calculate L_{ai} from expression (20).

For strip A_1 $\omega_1 = \frac{\pi}{\Delta}$, $\omega_2 = \frac{3\pi}{\Delta}$ (27b)

$$L_{a1} = \Delta \int_{\omega_1}^{\omega_2} \chi\left(\frac{2\pi k}{\Delta}, \omega\right) d\omega = 2\left(1{,}67 - 1{,}85 - \frac{2}{3\pi} + \frac{2}{\pi}\right) = 0{,}49.$$

For strip A_{-1} $\omega_1 = -\frac{3\pi}{\Delta}$, $\omega_2 = -\frac{\pi}{\Delta}$

$$L_{a,-1} = 2\left(1{,}85 - 1{,}67 + \frac{2}{\pi} - \frac{2}{3\pi}\right) = 1{,}21.$$

For the remaining strips

$$L_{a2}=0{,}09;\ L_{a,-2}=0{,}25;\ L_{a3}=0{,}036;\ L_{a,-3}=0{,}108;$$
$$L_{a4}=0{,}02;\ L_{a,-4}=0{,}06;\ L_{a5}=0{,}004;\ L_{a,-5}=0{,}052. \tag{27c}$$

The values of integrals for domains B_j are calculated from (21) and amount to

$$G_{bj}<3\pi\,[\operatorname{ctg}(0{,}05+k)\pi-\operatorname{ctg}(0{,}45+k)\pi]=58{,}5. \tag{27d}$$

In order to use (27) it is also necessary to calculate the maximum values of f_z (f_y is constant and equal to $30/2\pi$). These values correspond to points c_i in Fig.5.

It should be noted that in domains A_0, A_1, and $A_{-1}\,\omega_m$ the maximum of f_z is equal to zero. The values of $f_{z\,max}$ calculated from formula (25) for all the domains are contained in Table 2.

Let us now evaluate by their maximum the terms of formula (27) corresponding to domains B_∞ and $B_{-\infty}$. Let us note that these domains partly cover those of B_5 and B_{-5} and if (27) is made to include terms with subscripts [i]= 0,1,2,3,4, and [j]=1,2,3,4,5,∞, the overlapping of domains will raise the upper evaluation of integral (26).

Domains B_∞ and $B_{-\infty}$ consist of all the domains with subscripts [i]>4 and [j]>5. The evaluation is made in the following manner: instead of multiplying $(L_a\cdot M_a)_k$ or G_k by $f_y f_{z\,max}$ we multiply them by $f_y\cdot \frac{1}{|\omega_s|-|\omega_r|}\int_{|\omega_r|}^{|\omega_s|} f_z\,d\omega$, where ω_s corresponds to $f_{x\,max}$, and $[\omega_r]=[\omega_s]-\Delta\omega_k$ (k=i,j), where $\Delta\omega_k$ is the width of the corresponding domain (i.e., f_z for $[\omega_s]$ is larger than the maximum value of f_z in the domain under consideration with subscript k). This is possible since f decreases monotonically with a rising $[\omega]$.

This is seen more clearly from Fig.5, where the value of $\Delta\omega_{b4}$ for domain B_4 and $\Delta\omega_{a4}$ for domain A_4 are shown.

Since $L_{ai}\,M_{ai}$ decrease with a rising modulus of subscript [i], and G does not depend on j, we can substitute $L_{ai}\,M_{ai}$ ([i]>4) by the quantity $L_{a5}\,M_{a5}$ (or $L_{a,-5}\,M_{a,-5}$ for $B_{-\infty}$) and evaluate the addends in (26) corresponding to B_∞ in terms of their maximum value

$$R_{a5}=\frac{1}{\Delta\omega_{a5}}L_{a5}M_{a5}f_y\int_{7{,}1\frac{\pi}{\Delta}}^{\infty} f_z\,d\omega=0{,}28\cdot10^{-3}\frac{f_y}{\Delta\omega_{a5}}L_{a5}M_{a5};\quad R_{b5}=\frac{G}{\Delta\omega_{b5}}f_y\int_{7{,}1\frac{\pi}{\Delta}}^{\infty} f_z\,d\omega=0{,}28\cdot10^{-3}\frac{G}{\Delta\omega_{b5}} \tag{27e}$$

(for $B_{-\infty}$ subscript 5 is substituted by subscript -5 and the limits become negative).

Calculations show that $R_{a5}=0.1$; $R_{a,-5}=1.1$; $R_{b5}=R_{b,-5}=0.43$.

We insert the above data into (27) and obtain

$$D\delta Q=(18.200\ \text{min}^2)\ DzDy. \tag{27f}$$

Referred to the maximum value of the integral the maximum error is

$$Q_m=\frac{3\sigma_a}{y_{max}\ z_{max}\ T}=0{,}042\%. \tag{27g}$$

LITERATURE CITED

1. A. S. Nemirovskii. Measuring Instrument Integrators [in Russian] (Standartgiz, 1960).
2. A. M. Yaglom. Uspekhi matematicheskikh nauk, 1952, Vol. 7, No. 5/51.
3. V. V. Solodovnikov and A. S. Uskov. Statistical Analysis of Controlled Members [in Russian] (Mashgiz, Moscow, 1960).

LINEAR MEASUREMENTS

RADIOINTERFEROMETER FOR MEASURING LONG LENGTHS

G. S. Simkin, I. V. Lukin and L. I. Biryukov

Translated from Izmeritel'naya Tekhnika, No. 10,
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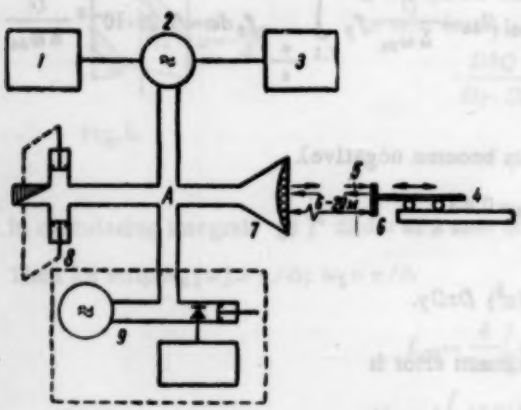
The exacting requirements specified at present in heavy and machine-tool engineering with respect to accuracy in manufacturing large details and units present measurement technology with the task of raising considerably the precision in measuring lengths up to 10 meters and more. For instance, GOST (All-Union State Standard) 2689-54 specifies for grade 1 shafts 10 000 mm in diameter a tolerance of 0.13 mm, and for holes of the same grade and diameter a tolerance of 0.18 mm, which in relative units amounts to $1.3 \cdot 10^{-5}$ and $1.8 \cdot 10^{-5}$ respectively. The equipment used for measuring such diameters should have an accuracy expressed in relative units of not less than $4 - 6 \cdot 10^{-6}$.

If we assume that the system designed to ensure uniform and accurate measurements of long lengths is greatly simplified and reduced to three stages (reference measures and instruments, working measures and instruments, and commodities), the error of the highest stage in this system would have to be smaller than $2 - 3 \cdot 10^{-6}$. In geodetic measurements the accuracy now required must not be below $1 - 0.8 \cdot 10^{-6}$. Thus, a 24 m surveyor's tape must be certified with an accuracy of $0.8 \cdot 10^{-6}$ [1].

A considerable improvement of accuracy in measuring short lengths (up to 100 mm) was attained by using light interference which provided accuracies of the order of $3 \cdot 10^{-7}$. The centimeter wavelength sources (generators) described in literature provide the opportunity of using interference methods for measuring lengths up to tens of meters and to anticipate a considerably improved accuracy in this range.

The Khar'kov State Institute of Measures and Measuring Instruments (KhGIMIP) has produced a double-beam radiointerferometer which operates in the centimeter waveband and is intended for testing end gauges and line measures. Below we describe the results of its testing.



The above radiointerferometer, whose schematic is shown in the attached figure, is based on a double-beam circuit with one terminated arm as used by Froome for measuring the propagation speed of electromagnetic waves (speed of light) [2,3].

Source (generator) 2 radiates centimeter wavelengths which are fed to divider A. Here half the power is radiated through a horn with lens 7 into outer space. The second half of the power is fed to a constant (terminated) arm of the interferometer where it is reflected from attenuator 8 and returned to divider A.

The power radiated into outer space is reflected from a flat mirror 5 and is again fed to divider A. Here both powers are added, in other words waveguide A is provided with interfering waves fed from the constant arm and reflected from the mirror. By displacing mirror 5 which is mounted on measuring carriage 4 it is possible to establish in waveguide A interference maxima and minima which can be observed on an oscilloscope by means of indicating system 9. (The indicating system is denoted by a dotted rectangle.)

System 3 stabilizes the frequency of generator 2 by means of a high-Q cavity resonator. The frequency of generator 2 is determined by means of measuring equipment 1, which consists of a highly-stable 100 kc quartz-crystal generator, frequency multipliers and a frequency comparison system.

Since in measuring any length the mirror is placed at two different distances from the horn, the signal received

from the horn for the first and second positions of the mirror has different amplitudes. The amplitude of the signal received from the constant arm is adjusted without changing its phase by means of attenuator 8, whose principle of operation is described in [3,4].

The reflecting mirror 5 is mounted on measuring carriage 4 which is displaced on guide rails along the measurement axis. The measuring carriage is used in conjunction with three microscopes, two of which serve to set the mirror in a given position and the third is used for testing line measurements. The tested surveyor's tape or tape measure is placed along guide rails 6 under the measuring carriage on special blocks.

For determining the length of end (or hole) gauges the guide rails carry two stays and a support with a measuring device (a clock-type indicator or a comparator). A detailed description of the interferometer construction and its measuring technique can be found in [4]. Here we shall only note the following.

1. The principle of measuring lengths by means of the radiointerferometer resembles in many ways the absolute measurement of length on an optical interferometer, for instance, of the Kesters type [5].

2. Since the wave length and hence the frequency of electromagnetic oscillations radiated by the radiointerferometer generator does not remain strictly constant as in the case of an optical interferometer, the radiointerferometer frequency f is measured with great precision and its wavelength λ is determined from the relation:

$$\lambda = \frac{c}{nf}, \qquad (1)$$

where c is the speed of light; n is the refractive index of air.

3. The actual value of the measured length referred to normal conditions (t = 20°C, P = 760 mm Hg, and the water vapor tension of 10 mm Hg) is determined from the relationship

$$L_x = L_N + \Delta m \frac{\lambda}{2} - A \pm \Delta L_t \pm c_n + \delta, \qquad (2)$$

where L_N is the nominal value of the measured length or its approximate value obtained from rough measurements; $\Delta m\lambda/2$ is the calculated fraction of a millimeter for the nominal or approximate value of the measured length; A is the reading of the measuring device (indicator, comparator or microscope); ΔL_t is the correction for the linear expansion of the measured length; c_n is the correction for the refractive index of dry air and water vapor; δ is the diffraction correction.

Since the refractive index depends on temperature and pressure, a table of refractive indexes was compiled for various values of t and P. The computing formulas for t and P were taken from [6]. The diffraction correction δ was determined from the computing formulas derived in [7]. In order to simplify the calculation of L_t, c_n and δ nomograms were drawn which provide a rapid evaluation of these quantities.

The radiointerferometer was used for repeated measurements of a 12 m surveyor's tape, a 20-meter 1st grade tape measure and an 8-meter hole gauge. Test have shown that the radiointerferometer can be used successfully for measuring lengths up to 30-40 m.

It should be noted that the radiointerferometer was used under relatively unfavorable conditions: the premises in which it was used did not provide the required stable ambient conditions, during measurements temperature humidity variations were observed. In order to reduce the effect of the above variations special steps were taken. Thus, before starting measurements the air was carefully mixed for 1-1.5 hours by means of several fans. Moreover, the temperature of the air and the gauge was measured with several thermometers placed along the measured length. Humidity was also determined in three places along the room. The above precautions made it possible to reduce considerably the measurement error due to the surrounding conditions.

In order to reduce the effect of the waves reflected from the surrounding objects, the floor, ceiling and walls, it was found necessary to place and orientate wooden strip absorbers and special shields in such a manner as to scatter at random the waves reflected from them. Moreover, each length was measured twice with a phase shift of $\lambda/4$ between the two measurements. This technique reduced considerably the effect of scattered readiations on the accuracy of measurements.

Table 1 shows the results of determining the components of the quadratic mean error in a 12 m length expressed in relative units. Tables 2 and 3 show the results of repeated measurements of a surveyor's tape and a grade 1 tape

measure respectively in the interval of 18 - 6 m. The quadratic mean error of measurements obtained on the basis of Tables 1,2, and 3 amounts to $1.6\text{-}2.0 \cdot 10^{-6}$.

TABLE 1.

No.	Classification of errors	Quadratic mean error σ_i in relative units
1	Error in determining the speed of light.	$4 \cdot 10^{-7}$
2	Error in determining the generator frequency.	$4 \cdot 10^{-7}$
3	Error in determining the refractive index of dry air	$2 \cdot 10^{-7}$
4	Error in determining the refractive index of water	$5 \cdot 10^{-7}$
5	Error due to the inaccurate knowledge of the measured object's linear expansion coefficient	$5 \cdot 10^{-7}$
6	Error of the measuring device	$1 \cdot 10^{-7}$
7	Error in determining the interference minimum.	$3 \cdot 10^{-7}$
8	Error in setting the microscope to a graduation when testing line measures	$4 \cdot 10^{-7}$
9	Error due to the lack of parallelism between the axis of the wave front and that of the measured object	$6 \cdot 10^{-7}$
10	Error due to the reflection of radio waves from extraneous objects	$7 \cdot 10^{-7}$
11	Error due to the variation in the length of the constant arm during measurements.	$3 \cdot 10^{-7}$
12	Error due to the possible change in the phase produced by the interference attenuator	$4 \cdot 10^{-7}$
13	Error in determining the diffraction correction	$8 \cdot 10^{-7}$

The reference grade 1 tape measure was certified by the All-Union Scientific Research Institute of Metrology (VNIIM). The length of the tape measure in the interval of 18 - 6 m provided in the VNIIM certificate amounted to 12 000,40 mm. Thus the discrepency in the measurement of this length by means of radiointerferometer and by the VNIIM amounted only to 0.04 mm.

A further increase in the accuracy of radiointerferometer measurements of long lengths can be attained by improving the conditioning of the premises in which the measurements are carried out, by raising the accuracy in measuring the refractive index of water vapor, by a more precise evaluation of the diffraction correction, as well as by further improvement in the design of certain radiointerferometer units.

At present the KhGIMIP is working on a further improvement of accuracy in length measurements. It is hoped to attain an accuracy of not less than $5\text{-}2 \cdot 10^{-7}$.

TABLE 2.

Date of measurement in 1960	Measurement number	Measured value of tape in mm
11/X	1	11999,88
	2	61
	3	61
13/X	1	56
	2	58
	3	58
	4	57
15/X	1	63
	2	59
	3	64
	4	60
	5	61
	6	60
17/X	1	58
	2	56
	3	57
	4	61
	5	59
19/X	1	63
	2	64
	3	63
	4	62
21/X	1	62
	2	62
	3	63
	4	61
	5	63

$L_m = 11999{,}60$ mm, $\sigma = \pm 2 \cdot 10^{-6}$.

TABLE 3.

Date of measurement in 1960	Measurement number	Measurement results in mm
27/X	1	12000,44
29/X	1	42
	2	42
	3	39
31/X	1	42
	2	47
	3	45
	4	46
1/XI	1	45
	2	44
	3	43
	4	45
2/XI	1	42
	2	45
	3	44
	4	44
3/XI	1	46
	2	45
	3	44
	4	45
	5	46
4/XI	1	46
	2	48
	3	48
	4	44

$L_m = 12000{,}44$ mm, $\sigma = \pm 1{,}6 \cdot 10^{-6}$.

LITERATURE CITED

1. V. A. Barinov. Modern Standards of Length [in Russian] (VNIIM Press, Leningrad, 1941).
2. K. D. Froome. Proceedings of the Royal Society, 1952, ser. A, Vol. 213, No. 1112.
3. K. D. Froome. Proceedings of the Royal Society of London, 1954, Vol. 223.
4. G. S. Simkin, I. V. Lukin, and L. I. Biryukov. Metrological Testing of the Radiointerferometer [in Russian] (Report D-9/16-60, KhGIMIP, 1960).
5. M. F. Romanova. Interference of Light and its Applications [in Russian] (ONTI, 1937).
6. L. Essen and K. D. Froome. Nature, 1951, Vol. 167, No. 4248.
7. G. S. Simkin. Izmeritel'naya tekhnika, 1960, No. 4.

INVESTIGATING THE KINEMATIC ERROR IN A HYDRAULIC COMPARATOR

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In recent years the hydraulic method of measuring dimensions has again attracted the attention of Soviet and foreign investigators. The kinematic error in hydraulic comparators plays an important part in determining the final judgement on the advisability of using the hydraulic method and on selecting a suitable arrangement for the instrument.

In the schematic of the hydraulic instrument (Fig. 1a) the chamber is closed by a piston connected to a measuring rod. When the rod is displaced by s the level of the liquid in the measuring tube varies by h. Since the liquid is virtually incompressible and the deformations in the chamber walls and the piston bottom due to the variation in the head of the liquid are negligible, there will be no kinematic error in the piston comparator and its gear ratio will depend only on the ratio of the chamber and measuring tube diameters

$$K=\frac{h}{s}=\frac{D_K^2}{d_T^2}. \tag{1}$$

The chamber of actual hydraulic comparators is covered by a thin elastic diaphragm, which may have a rigid center (Fig. 1b). In this case the diaphragm bending factor φ should be included in expression (1)

$$K=\varphi\frac{D_K^2}{d_T^2}. \tag{2}$$

It is obvious that a kinematic error will appear in hydraulic comparators if φ has a nonlinear relationship to the measuring rod displacement s.

I. E. Gorodetskii [1] and V. G. Shtein [2] assume that a deformed diaphragm can be represented by a cone whose height is equal to the displacement of the measuring rod, and on this basis estimate the diaphragm bending factor to be $^1/_3$ in the absence of a rigid center.

With a rigid center we have:

$$\varphi=\frac{1}{3}(1+\rho+\rho^2), \tag{3}$$

where ρ is the ratio of the rigid center diameter to that of the chamber, $\rho = D_n/D_K$.

A. T. Draudin [3] determines the value of φ from formula:

$$\varphi=\frac{1}{3}(1+2\rho^2). \tag{4}$$

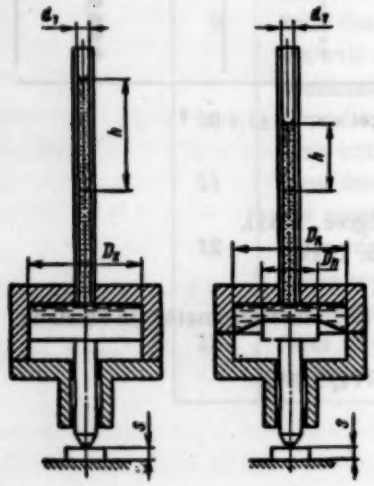

Fig. 1.

In all these formulas the value of φ is not related to measuring rod displacement s. The authors assume that there is no kinematic error in the diaphragms of hydraulic comparators and the gear ratio depends only on the geometrical parameters D_K, D_n, and d_T of the instrument. In the description of the Hoffmann Company's hydraulic comparator [4] it is noted, contrary to the above opinion, that the displacement of the measuring rod and the variation of the liquid level in the measuring tube do not possess a strictly linear relationship, i.e., there exists a certain kinematic error.

Let us derive a formula for factor φ in the case of a perfectly elastic diaphragm which meets the following requirements: 1) the diaphragm is slanting with respect to plane XOY (Fig. 2); 2) the diaphragm is only being stretched; 3) the tensioning of the diaphragm is constant in all directions and does not depend on its deformation.

The sagging z of a perfectly elastic diaphragm meets Poisson's equation

$$\frac{\partial^2 z}{\partial x^2}+\frac{\partial^2 z}{\partial y^2}=\frac{p}{T}. \tag{5}$$

where p is the difference in the pressure of the two media separated by the diaphragm; T is the tensioning of the diaphragm.

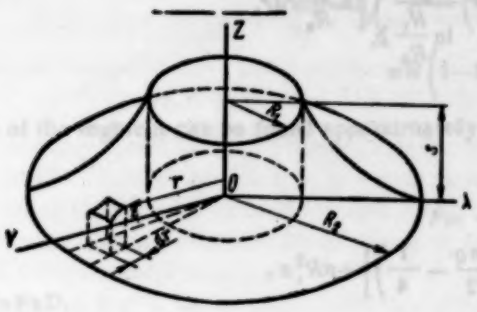

Fig. 2.

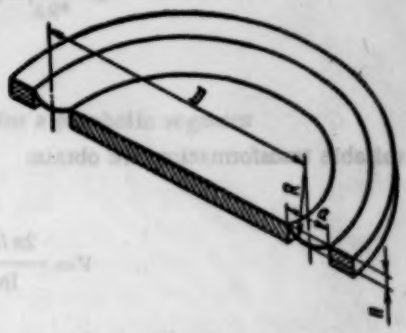

Fig. 3.

In order to simplify the computations let us assume that the pressure difference p does not exist. Then the sagging z will satisfy the Laplace equation

$$\frac{\partial^2 z}{\partial x^2}+\frac{\partial^2 z}{\partial y^2}=0. \tag{6}$$

It is required to find the shape of the diaphragm with a rigid center in the form of a circle, i.e., to solve the Laplace equation for a circular area with the following limiting conditions: at the outer circumference $z=0$; at the inner circumference $z=s$, where s is the displacement of the rigid center.

Since the assumed limiting conditions refer to two circles whose centers are located on axis OZ, the diaphragm surface will be represented by a solid of revolution about axis OZ.

Let us write (6) in polar coordinates

$$r^2\frac{\partial^2 z}{\partial r^2}+r\frac{\partial z}{\partial r}+\frac{\partial^2 z}{\partial \theta^2}=0, \tag{7}$$

where r is the variable radius; θ is the rotation angle of the variable radius.

Now the limiting conditions will take the form: at the outer circumference $z(R_2, \theta)=0$, at the inner circumference $z(R_1, \theta)=s$. The limits within which the independent variables r and θ vary are:

$$R_1<r<R_2 \qquad 0<\theta<2\pi. \tag{7a}$$

Since the surface of the membrane is represented by a solid of revolution, variable z does not depend on angle θ and is a function of a single variable r. Then (7) will assume the form

$$r^2\frac{d^2 z}{dr^2}+r\frac{dz}{dr}=0. \tag{8}$$

By solving (8) for given limiting conditions (by substituting $r=e^t$) we obtain an equation for the generating line of the diaphragm.

$$z=s\cdot\frac{\ln\frac{r}{R_2}}{\ln\frac{R_1}{R_2}}. \tag{9}$$

Let us now calculate the volume displaced by the diaphragm in the measuring tube when the rigid center is displaced by s.

$$V=\pi R_1^2 s+\int_{R_1}^{R_2} z2\pi dr=\pi R_1^2 s+\frac{2\pi s}{\ln\frac{R_1}{R_2}}\int_{R_1}^{R_2}\ln\frac{r}{R_2}rdr. \tag{9a}$$

After suitable transformations we obtain:

$$V=\frac{2\pi R_2^2 s}{\ln\varrho}\left[-\frac{1}{4}-\varrho^2\left(\frac{\ln\varrho}{2}-\frac{1}{4}\right)\right]+\pi R_1^2 s, \tag{10}$$

where $\rho = R_1/R_2$.

Factor φ represents the ratio of volume V displaced by the diaphragm in the measuring tube to volume V_0 displaced in the measuring tube by a piston with radius R_2.

$$\varphi=\frac{V}{V_0}=\frac{\frac{2\pi R_2^2 s}{\ln\varrho}\left[-\frac{1}{4}-\varrho^2\left(\frac{\ln\varrho}{2}-\frac{1}{4}\right)\right]+\pi R_1^2 s}{\pi R_2^2 s}, \tag{11}$$

whence

$$\varphi=\frac{\varrho^2-1}{2\ln\varrho}.$$

Formula (11) has been derived for the case when there is no pressure difference. In fact there will always be a pressure difference in hydraulic comparators; moreover, if the head of liquid is constant (for instance, in a horizontal position of the measuring tube) the pressure difference will remain constant.

Formula (11) also holds for a constant pressure difference, since the additional deformation of the diaphragm due to the head of liquid provides a constant additional volume V' (independent of s).

This follows from the principle of the independent action of forces, which is applicable in this instance, since the equations characterizing the shape of the diaphragm both without a pressure difference (Laplace equation) and with a pressure difference (Poisson equation) are linear differential equations.

It will be seen from (11) that in the case of a constant pressure on the diaphragm surface the value of factor φ does not depend on the measuring rod displacement s and there is no kinematic error in the hydraulic comparator. However, in existing hydraulic comparators the head of liquid varies with the displacement of the measuring rod and the pressure difference depends on the sagging of the diaphragm. In this case the formula for factor φ must be made more precise, since the changed pressure provides an additional deformation of the diaphragm, thus making the volume of liquid displaced in the measuring tube smaller than that which would have been displaced at a constant pressure.

At a varying pressure the gear ratio of a hydraulic comparator is:

$$K=\frac{h}{s}=\varphi'\frac{D_K^2}{d_T^2}=\frac{\varphi\frac{\pi D_K^2}{4}s-V''}{\frac{\pi D_K^2}{4}s}\cdot\frac{D_K^2}{d_T^2}, \quad \text{whence} \quad h=\frac{\varphi\frac{\pi D_K^2}{4}s-V''}{\frac{\pi d_T^2}{4}}. \tag{12}$$

where V" is the volume due to an additional deformation of the diaphragm caused by h.

Let us find this volume. If ρ does not differ considerably from unity, it is possible in calculating volume V" to take into account the diaphragm curvature $1/R$ only at the axial cross section. Then the Poisson equation will assume the form

$$\frac{1}{R}=\frac{p}{T} \quad \text{or} \quad \frac{1}{R}=\frac{h\gamma}{T}, \tag{13}$$

where $\underline{h}$ is the head of the liquid; λ is the specific gravity of the liquid.

The height of the segment (Fig.3) is equal to:

$$H=R-\sqrt{R^2-\left(\frac{a}{2}\right)^2}=R-R\sqrt{1-\frac{a^2}{4R^2}}\approx \tag{13a}$$

$$\approx R\left(1-1+\frac{a^2}{8R^2}\right)=\frac{a^2}{8R}.$$

The area of the segment can be found approximately from the formula for a parabolic segment

$$F=\frac{2}{3}aH=\frac{a^3}{12R}. \tag{13b}$$

Then $V''=F\pi D$.

By substituting the value of F and replacing R by its value obtained from (13) we have

$$V''=\frac{1}{12}\cdot\frac{a^3\gamma\pi D}{T}h. \tag{14}$$

With the above assumptions the additional volume V'' has a linear relationship to $\underline{h}$.

Let us now find how this situation will affect the value of the diaphragm bending factor.

By inserting (14) into (12) and solving it with respect to $\underline{h}$ we find

$$h=\frac{\varphi\frac{\pi D_K^2}{4}s}{\frac{\pi d_T^2}{4}+\frac{1}{12}\cdot\frac{a^3\gamma\pi D}{T}} \tag{14a}$$

or

$$\frac{h}{s}=\frac{\varphi}{1+\frac{1}{3}\cdot\frac{a^3\gamma D}{T\cdot d_T^2}}\cdot\frac{D_K^2}{d_T^2}. \tag{14b}$$

By comparing the above equation with (2) and (1) we obtain:

$$\varphi'=\frac{\varphi}{1+\frac{1}{3}\cdot\frac{a^3\gamma D}{Td_T^2}}. \tag{15}$$

It will be seen from formula (15) that with the above assumptions the value of factor φ' does not depend on the displacement of the measuring rod and hence there is no kinematic error even with a varying head of liquid. The value of factor φ' differs from that of the diaphragm bending factor φ obtained at a constant pressure and decreases rapidly with a rising annular gap $\underline{a}$.

The above conclusions were verified experimentally.

The rod displacement (Fig.4) was measured on optikator 8 mounted on the lower holder 2 of an extensometer. In order to provide the required measuring effort for the optikator in a reversed position, an additional load 9 was provided for the measuring rod of the optikator. This equipment was used for investigating the relation between the liquid level displacement in a hydraulic comparator and displacement $\underline{s}$ of the rigid center of the diaphragm, from which the gear ratio K and the value of factor φ were calculated.

Tests were carried out with a variable $h = f(s)$ and a constant $h = \text{const}$ head of liquid. In the first instance the instrument was read by observing the miniscus of the liquid column, and in the second instance the entire capillary tube was filled with water including a portion of the cup at its top end; readings were obtained from the position of the air bubble. The error due to temperature was compensated in the hydraulic instrument according to the method suggested by the author [5,6].

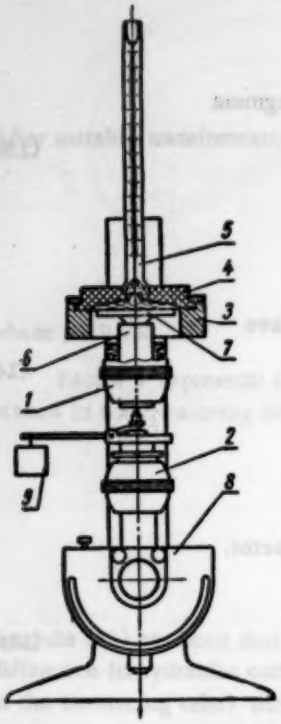

Fig. 4. Schematic of the experimental equipment for determining the relation $h = f(s)$. 1) Upper bracket with an extensometer holder; 2) lower bracket with an extensometer holder; 3) base of the hydraulic comparator; 4) chamber; 5) measuring tube; 6) rod; 7) replaceable rigid diaphragm center; 8) optikator, and 9) weight.

A rubber diaphragm 0.16 mm thick and a metal (nickel) diaphragm 0.048 mm thick were tested.

From the curves of the relationship $h = f(s)$ obtained by the author for a rubber diaphragm at various values of ρ it will be seen that a linear relationship of $h = f(s)$ prevailed with a constant head of water for all the values of ρ, i.e., there was no kinematic error. In the case of a variable head of water there was no kinematic error at $\rho = 0.935$ and $\rho = 0.9$, but for $\rho = 0.8$ a certain nonlinearity was observed in the relationship $h = f(s)$, which increased with a decreasing ρ. For a metal diaphragm and all the values of ρ from 0 to 0.8, no kinematic error was observed either in the case of a constant or variable pressure on the diaphragm.

A comparison of curves $\varphi = f(\rho)$ obtained by the author experimentally and by calculation shows that the experimental curves for a constant pressure are in better agreement with the curve plotted from (4), and that the curve obtained for the rubber diaphragm at a variable pressure is in good agreement with the theoretical curve.

The above theoretical and experimental investigations have shown that there is no kinematic error in hydraulic comparators at constant pressure. The value of factor φ for a variable pressure is smaller than that for a constant pressure and decreases rapidly with a decreasing ρ.

Conclusions. In order to eliminate the kinematic error and raise factor φ, and hence raise the sensitivity of the instrument, it is necessary to use hydraulic comparators which provide a constant pressure on the diaphragm due to the liquid head independently of the displacement of the instrument's measuring rod.

LITERATURE CITED

1. L. E. Gorodetskii. Basic Technical Measurements [in Russian] (Mashgiz, Moscow, 1950).
2. V. G. Shtein. Izmeritel'naya tekhnika, 1959, No. 12.
3. L. E. Gorodetskii, editor of collection entitled "Interchangeability and Measurement Techniques" [in Russian] (No. 18, NIBV MSS, 1948).
4. The Production of Ball and Roller Bearings. Methods Employed by the Hoffmann Manufacturing Co. Ltd., Machinery, Vol. 91, No. 2346, 1957, November 1.
5. V. V. Matveev. Compensation of Temperature Errors in Instruments with Hydraulic Transmission [in Russian] (Works of the Saratov Institute of Road Transport, Vol. 13, Saratov, 1955).
6. V. V. Matveev. Temperature Error in Instruments with Hydraulic Transmission. Interchangeability and Technical Measurements [in Russian] (Collection of Higher Educational Institutions MVTU-STANKIN, No. 2, Mashgiz, Moscow, 1959).

All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

MEASUREMENTS ON A MIS-11 SET OF THE ROUGHNESS OF INTERNAL SURFACES

M. R. Besser and N. A. Manikhin

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 14-15, October, 1961

A double microscope MIS-11 can be used for checking the surface roughness of articles with a surface finish ranging from grade 3 to grade 9. An essential defect of this instrument consists in the necessity of cutting open articles whose internal surface (the surface of openings) has to be tested. In bearing manufacture this procedure involves considerable expenditure, since cutting of hardened races is difficult and finished articles have to be discarded.

The author has modified the construction of microscope MIS-11 in such a way as to be able to meaure the roughness of both external and internal surfaces in holes with diameters from 90 mm up and a depth of 60 mm. In the adapted instruments all the units remain unchanged (Fig. 1), only the position of the microscope tubes and that of the objectives with respect to the tubes are changed.

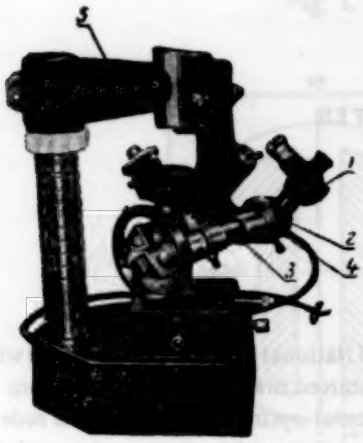

Fig. 1.

For evaluating surface roughness of articles exceeding 150 mm diameter it is also desirable to change the construction of bracket 5, which should be made straight instead of being bent, since with the existing bracket it might be impossible to place the articles on the microscope stage.

For convenience of operation the eyepiece micrometer 1 is mounted on a slanting single eye piece extension 2 type AU-9 fixed to the visual tube 3 by means of coupling 4.

The schematic of the instrument is shown in Fig. 2. In order to be able to place the objectives inside the openings of the articles, it is necessary to mount the visual 1 and illuminating 2 tubes horizontally by means of holders 3 fixed to mountings 10 and 11. The mountings correspond to the external dimensions of the illuminating and visual tubes of the microscope and are fixed instead of them into the body of the microscope. The threaded holes of the illuminating and visual tubes, which are designed to take the objectives, are used for screwing into them a threaded bush 9, whose free end is screwed to a prism-holder 8 which has a threaded hole for the objectives. The prism-holder contains a rectangular prism 4 which changes the direction of the beam. The prism-holders are fixed in position by lockout 7.

The objectives of the visual and illuminating tubes are mounted with their optical axes at an angle of 45° to the horizontal plane in the following manner: the plane of each prism-holder which serves as a base for the objective is mounted by means of grade 1 angle gauges at an angle of 45° to the plane of the microscope stage. In this position the visual and illuminating tubes are fixed by means of adjusting pins placed in the grooves of holders 3.

In order to be able to place in a 90 mm diameter hole objectives with F = 8.16 and F = 4.25 flats have to be cut in them at an angle of 70 and 60° respectively. Objectives with F = 25 and F = 13.89 need not be altered.

The microscope is adjusted by means of screw 6, nut 5, rack 12 and micrometer screw 13 in a manner similar to that used in microscope MIS-11. The measurement of the surface roughness and its photographing are made in a similar manner to that used in a normal MIS-11 microscope.

It was established during the adjustment of the instrument that the value of $E = 1/v$ (v is the linear magnification of the objective with an additional lens in the visual tube) had altered in measuring the roughness of internal surfaces. The value of E for each pair of objectives was determined from the formula:

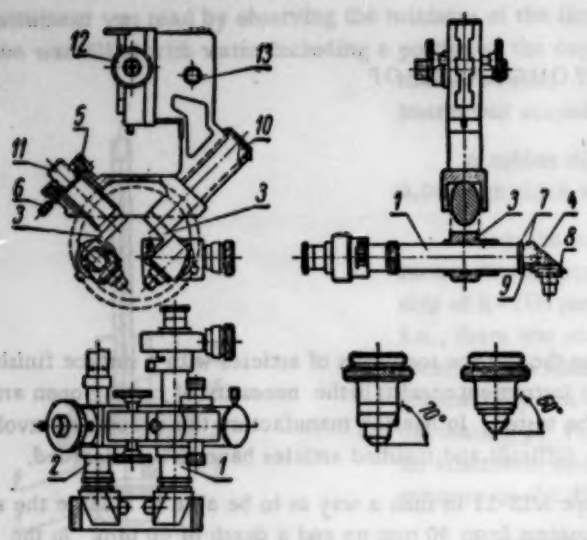

Fig. 2.

$$E=\frac{Tz}{A\cdot 0{,}01}, \quad (1)$$

where T is the multiplying factor of the microscope objective; A is the number of calibrations on the thimble of the eyepiece micrometer (the difference in the readings obtained for two points of coinciding crosshairs); 0.01 is the multiplying factor for one measuring thimble division in mm.

In determining E we obtained: for objectives with F = 8.16 of a standard microscope E is equal to 0.057, the E' of a microscope for measuring the roughness of internal surfaces is equal to 0.046, for objectives with F = =4.25 we have E = 0.029 and E' = 0.022.

Tests of the roughness of grades 7 and 8 internal surfaces made on a standard microscope and a microscope adapted for measuring internal surfaces provided identical results.

MEASURING SMALL INTERNAL DIMENSIONS ON AN OPTIMETER

P. U. Markov

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pp. 16-17, October, 1961

The area opticomechanical laboratory of the Tomsk Sovnarkhoz (Council of National Economy) was faced with the problem of measuring small holes with high accuracy when the GPZ-5 plant started manufacturing instrument bearings. A measuring method was developed based on the utilization of a horizontal optimeter and brackets redesigned for this purpose. Normal brackets supplied with the horizontal optimeter are designed to measure internal dimensions from 13 mm upwards.

Figs. 1 and 2 show measuring brackets with a redesigned feeler and an arrangement for measuring holes 2 mm in diameter. We found spring steel granded 65 G with a hardness of HB = 250 to be the most suitable material for these brackets. It is inadvisable to harden the feeler, since it then becomes impossible to press in satisfactorily the measuring ball. Special attention should be paid to the clamping of this ball. For a considerable time we were unable to obtain stable readings on the optimeter, owing to the unsatisfactory clamping of the ball.

It is very difficult to fix small bearing races on the optimeter stage. We produced for this purpose a split socket which can easily be fixed to the stage (Fig.3).

For measuring holes 1.5 mm in diameter this method and technique were unsatisfactory, since the rigidity of the brackets was then considerably reduced. These holes were measured in two stages, as shown in Fig.4. For this purpose a special split socket was produced with cut-off edges and slots, and placed between two sidepieces which are ground in to block gauges of dimension C.

Dimensions A and B are then measured in the normal manner.

The required diameter of the ring will then be equal to

$$D=A+B-C. \quad (1)$$

The cross sectional dimensions of the bracket feelers used for this purpose are shown in Fig.5.

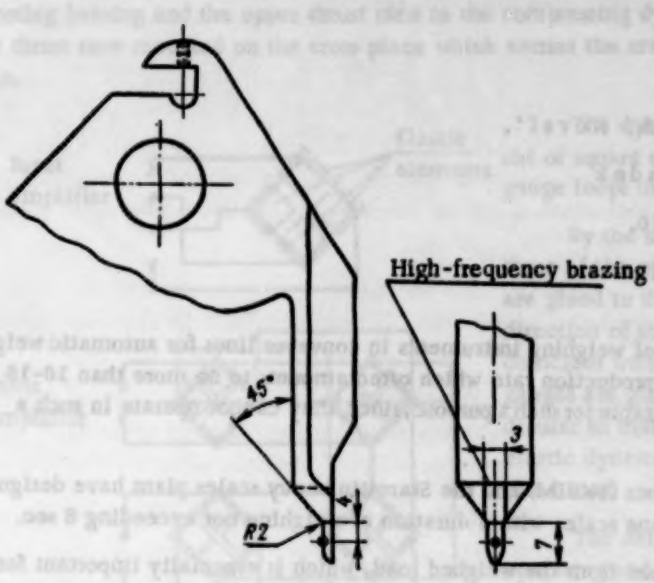

Fig. 1.

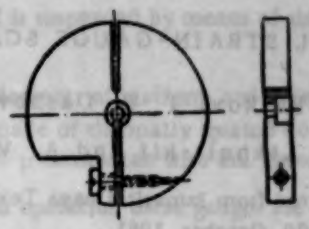

Fig. 3.

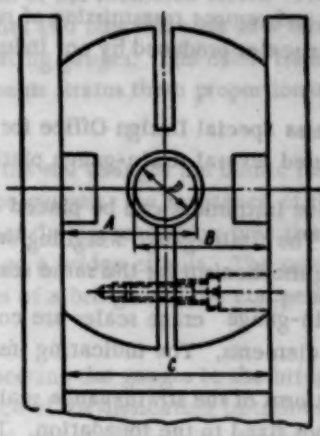

Fig. 4.

Fig. 2.

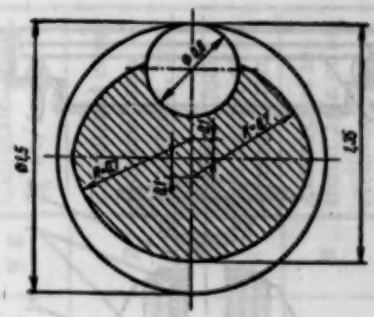

Fig. 5.

The calculations and tests carried out in the laboratory have shown that the above equipment and measurement techniques provide measurements of holes above 1.5 mm with a reading instability of the order of 0.5 μ.

ELECTRICAL STRAIN-GAUGE SCALES

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Production automation requires the incorporation of weighing instruments in conveyor lines for automatic weighing, recording and remote transmission of results at the production rate which often amounts to no more than 10-15 sec. The lever scales produced by our industry are unsuitable for such a purpose, since they cannot operate in such a short time.

The Odessa Special Design Office for Test Machines (SKBIM) and the Starostin heavy scales plant have designed and manufactured several strain-gauge platform and crane scales with a duration of weighing not exceeding 8 sec.

The above instrument can be placed at any distance from the weighed load, which is especially important for crane scales. The strain-gauge weighing devices do not exceed 3-5% of the weight of platform scales, whereas the lever weighing mechanism for the same scales amounts to 20-25%.

The strain-gauge crane scales are compact and small since they consist only of a weight-carrying device and dynamometer elements. The indicating instrument is located in the crane driver's cabin.

The platform of the strain-gauge scales (Fig. 1) rests on four weight-carrying devices which are mounted at its corners on stands fixed to the foundation. The loading effort from the platform is transmitted through a rod and a spherical support to a cushion which rests on four compressing dynamometer elements which are mounted on a base fixed to a plate of the stand.

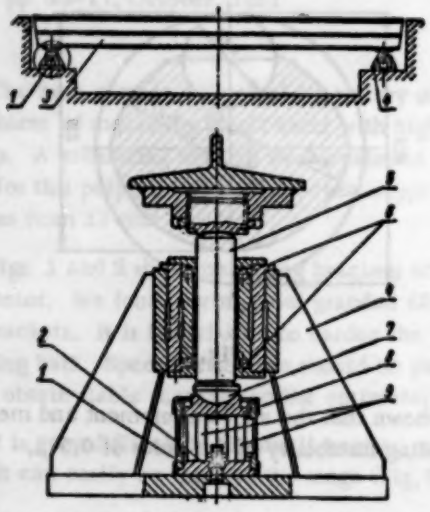


Fig. 1. Strain-gauge platform scales: 1) Weight-carrying devices; 2) foundation; 3) platform; 4) stand; 5) rod; 6) guiding bearings; 7) spherical support; 8) cushion; 9) dynamometer elements.

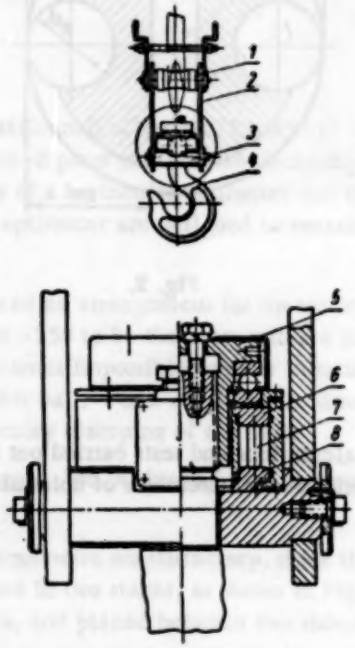


Fig. 2. Crane scales: 1) Pin; 2) sidepiece; 3) cross piece; 4) hook; 5) nut; 6) supporting bearing and the upper thrust race; 7) dynamometer elements; 8) lower thrust race.

In the crane scales (Fig. 2) the effort of the load suspended on the hook is transmitted through the nut, the supporting bearing and the upper thrust race to the compressing dynamometer elements. These elements rest on the lower thrust race mounted on the cross piece which carries the crane hook and is suspended by means of sidepieces and a pin.

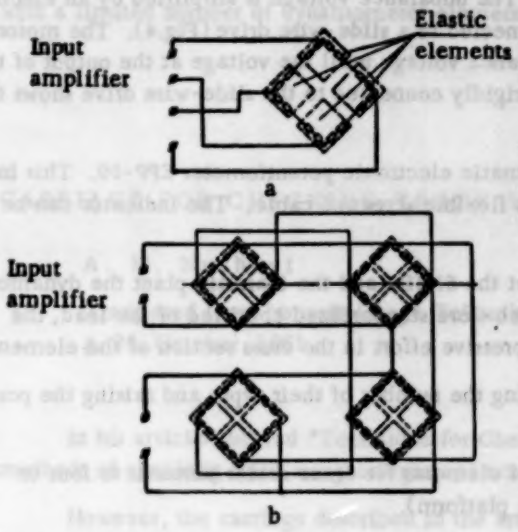


Fig. 3. Method of connecting the grids to the bridge arms.

The dynamometer elements of platform and crane scales consist of square elastic rods made of thermally treated 40 Kh steel. Strain-gauge loops made of 25-30 μ constantan wire are glued to their sides.

By the nature of their operation these gauges are divided into those of the operating and compensation types. The operating gauges are glued to the opposite sides of the rods in such a manner that the direction of their length coincides with that of the rod, i.e., that it coincides with the direction of the measured effort. The compensation gauges are glued to the other two opposite sites in a direction perpendicular to that of the operating gauges. The effort transmitted by the elastic dynamometer elements strains them proportionately to the applied load.

The deformation of the rod changes the ohmic resistance of the operating and compensation gauges: the resistance of the operating gauges decreases and that of the compensation type rises slightly. The gauges are connected to a bridge circuit. The operating gauges form the two opposite sides of a bridge and the compensation gauges the remaining two arms.

The method of connecting the gauges to the bridge arms may differ, depending on the number of elastic elements and the input resistance of the indicating instrument. Fig.3a shows a method of connecting gauges to the bridge used in crane scales and one of the weight-carrying devices of platform scales, which consist of four such dynamometer elements. Fig. 3b shows the method of connecting gauges of four weight-carrying devices in platform scales.

Weight capacity, kg-wt	Number of dynamometer elements	Weight capacity kg-wt	Number of dynamometer elements	Weight capacity, kg-wt	Number of dynamometer elements	Loading per dynamometer element kg-wt	Calculated stress, kg-wt/mm²	Calculated cross sectional area of an element, mm²	Cross sectional dimensions of an element, mm	Actual cross sectional area of an element, mm²	Actual stress, kg-wt/mm²
4000	4	8000	8	16000	16	1000	16	64	8×8	64	15.625
5000	4	10000	8	20000	16	1250	20				19,531
6400	4					1600	16				16,000
		12500	8	25000	16	1562,5	16	100	10×10	100	15,625
8000	4	16000	8	32000	16	2000	20				20,000
10000	4	20000	8	40000	16	2500	16	160	12,5×12,5	156,25	16.000
12500	4	25000	8	50000	16	3125	20				20,000
16000	4	32000	8	64000	16	4000	16	250	16×16	256	15,625
20000	4	40000	8	80000	16	5000	20				19,531
25000	4	50000	8	100000	16	6250	16	400	20×20	400	15,625
				125000	16	7812,5	20				19,531
32000	4	64000	8			8000	20				20,000
40000	4	80000	8	160000	16	10000	16	640	25×25	625	16,000
50000	4	100000	8	200000	16	12500	20				20,000

The above method of connections measures the actual weight even with a nonuniform distribution of the load either among the weight-carrying devices or among separate dynamometer elements.

In the absence of a load the bridge is balanced and the products of the resistances in opposite arms are equal to each other. When the load is being weighed the strain-gauge bridge becomes unbalanced, and across its measuring diagonal appears a voltage which corresponds to the applied load. The unbalance voltage is amplified by an electronic amplifier and fed to a reversible motor whose axle is rigidly connected to a slide-wire drive (Fig.4). The motor operates the slide-wire compensating the strain-gauge bridge unbalance voltage until the voltage at the output of the amplifier becomes equal to zero. The indicating pointer which is rigidly connected to the slide-wire drive shows the weight on the instrument scale.

The indicating and recording instrument is based on the automatic electronic potentiometer EPP-09. This instrument is connected to the strain-gauge transducers by means of a flexible screened cable. The indicator can be mounted in any place convenient for observation.

Since mass production of the strain-gauge scales has started at the SKBIM and the Starostin plant the dynamometer elements have been standardized. The basic parameters which were standardized consisted of the load, the number and dimensions of the elastic elements, and the mean compressive effort in the cross section of the element.

The elastic elements were standardized with a view to reducing the number of their types and raising the possibility of using the same elements in different types of scales.

The Design experience has shown that a convenient number of elements for crane scales amounts to four or eight, and for platform scales to sixteen (four for each corner of the platform).

The experiments carried out by the SKBIM have shown that the optimum mechanical stresses for the operation of the dynamometer elements are in the range of 16-20 kg-wt/mm^2. On the basis of these data a table has been compiled.

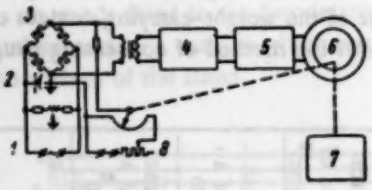


Fig. 4. Block-schematic of automatic electronic strain-gauge crane scales: 1) Zero setting; 2) compensation of the reactive component; 3) strain-gauge bridge; 4) amplifier; 5) phase detector; 6) reversible motor; 7) instrument detector; 8) setting of the multiplying bridge.

The scales have been divided by their weighing capacity into three design groups: the first group consists of strain-gauge crane scales with four elastic elements and a range of 4 to 50 tons; the second group consists of crane scales with a range of 8 to 100 tons, and the third of platform scales with a range of 16 to 200 tons (factory scales with a weighing capacity exceeding 200 tons are rare and were not included in the standardization).

The minimum weighing capacities (4 tons for the crane and 16 tons for the platform scales) are determined by the geometrical dimensions of the elastic element sides. The minimum width of an elastic element side on which it is possible in practice to glue loop gauges amounts to 8 mm. For smaller loads it is necessary to use dynamometer elements which operate with other types of deformations.

Each higher group of scales has double the number of elements, and twice the weight-lifting capacity of the lower group. Thus, the same loading per element is ensured for all three groups.

Since the weight-lifting capacity of the scales is spaced according to the tenth series of preferred numbers which have a factor of 1.25, the stresses of the elastic elements were chosen, in order to reduce their number, as two adjacent figures in the same series, namely, as 16 and 20 kg-wt/mm^2. This has made it possible to halve the number of the required types of elastic elements.

The cross sectional areas of dynamometer elements are shown in the table and correspond to their weight-lifting capacity, loads per element and stresses.

The size of an elastic element side is the square root of its cross section, i.e., it is the square root of a number in the fifth series, that is a number of the tenth series.

In compiling the series of preferred numbers certain round figures were taken, therefore the products and individual figures in a series do not always fully correspond to the series numbers given in GOST (All-Union State Standard) 8032-56. These inaccuracies can best be compensated by adjusting the stresses.

The actual stresses for the adopted dimensions of the strain-gauge element sides in all the instances are corrected by the same relative quantity (-2.4%).

The standardization of elastic elements according to a series of preferred numbers ensures the variation of all the calculated parameters of strain-gauge scales according to the same law, and provides a large variety of scales with a limited number of dynamometer element types.

CARRIAGE FOR CHECKING TRUCK WEIGHBRIDGES

A. M. Nuzhnyi

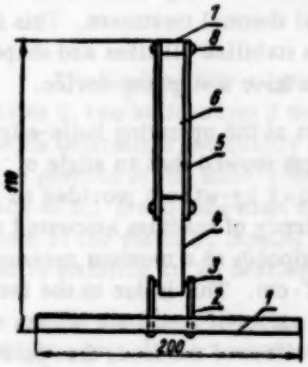
Translated from Izmeritel'naya Tekhnika, No. 10,
p. 20, October, 1961

In his article entitled "Technique for Checking Truck Weighbridges"* S. I. Gauzner examines the existing methods of checking truck weighbridges and considers I. S. Krever's method to be the simplest and most convenient.

However, the carriage described in the article and required for the application of this method is complicated in design, and therefore cannot be manufactured everywhere. Hence, the checking of truck weighbridges by I. S. Krever's method is not being widely applied.

A. D. Snagovsky's suggestion** that the end of the truck weighbridge balance beam be provided with a hole, knife-edge bearing and a link from which a scale-pan can be suspended, will require a lengthening of the beam, since with the existing design of the beam a pan cannot be suspended from it.

In order to avoid the necessity of providing the newly produced truck weighbridge beams with a knife-edge, and so as to cater for existing weighbridges without knife-edges, we suggest a simpler design for the carriage required for checking truck wieghbridges according to I. S. Krever's method (see Figure). This carriage can be produced in any weighing equipment repair workshop.



1) Pan; 2) link; 3) knife-edge; 4) plate; 5) sidepieces; 6) opening for beam; 7) distance piece; 8) holding screws.

The Alma-Ata GKL (State Inspection Laboratory) has produced 4 such carriages and by means of them is checking weighbridges in rural districts.

The possible reduction in weighbridge sensitivity when used with this carriage due to the apex of its knife-edge being below the line passing through the apexes of the resting and weight-carrying knife-edges on the beam was not observed in practice.

The above carriage could find wide application in the majority of the GKL's as well as in weight equipment repair plants.

Editorial Note. The editorial board considers that the Sverdlovsk branch of the VNIIM (All-Union Scientific Research Institute of Metrology), which has been entrusted with the drafting of instruction 15-52 for testing stationary scales, should test out A. M. Nuzhnyi's carriage and, if the author's claim of its high quality is confirmed, its description should be included in the instruction.

* Izmeritel'naya tekhnika, 1960, No. 3.
** Izmeritel'naya tekhnika, 1961, No. 1.

MECHANICAL MEASUREMENTS

PRECISION DEVICES FOR MEASURING SMALL MOMENTS

I. S. Demidov

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 20-24, October, 1961

The production of precision devices for measuring small moments due, for instance, to unbalances in systems of considerable weight, has up to the present time remained an unsolved problem in precision instrument-making. It is now necessary to have devices capable of measuring moments of the order of 0.001-0.002 g-wt·cm in tested components weighing up to 3000-6000 g.

A no less important characteristic of the equipment consists in the stability of its readings and an easy checking of its sensitivity and accuracy.

All these requirements are met by devices with knife-edge bearing which provide high sensitivity and stability of readings. Such a device is represented by a physical pendulum with a fulcrum consisting of the knife-edge and the bearing plate. Such systems are widely used in measuring instruments (metrological balances, gravimetric pendulums, etc.).

Taking into account the peculiarities of the tested systems we have developed and tested out two types of devices, with single and double knife-edges.

The single knife-edge device for testing moments (Fig.1) consist of stand 1, beam 4, bearing plate 2, and knife-edge 5. The balance beam carries a micro-scale 6 which is observed through optical system 7, and rods 8 for the load. Sensitivity is adjusted by means of spindles and weights 3 whose displacement varies the center of gravity.

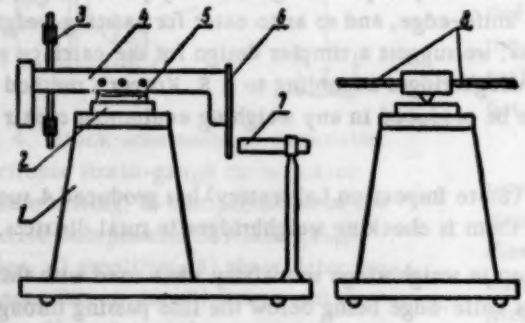


Fig. 1

The beam is made of a precision alloy brand ÉI-630 (superinvar) subjected to special thermal treatment. This is necessary in order to be able to stabilize all sizes and shapes of beams. The instrument must have a stopping device.

Investigation of the effect of the operating knife-edge angle on the stability on readings showed that an angle of $\gamma = 90°$ with a relative load of q=1 kg-wt/cm provided an unstable operation. The inconsistency of readings amounted to 4-5 min of the arc, which corresponds to a moment measurement error of 0.004-0.005 g-wt·cm. This is due to the fact that in the above case small particles of metal are broken off the sharp knife-edge under the effect of the load, thus producing micro irregularities in the knife-edge blade.

Stable instrument readings were obtained with a knife-edge angle of $\gamma = 120°$, when the inconsistency of readings did not exceed 1.5 min of the arc, which corresponds to a moment measurement error of 0.0015 g-wt·cm.

We developed the following method for determining the unbalance moment of systems.

Let us express the restoring moment M_r of a physical pendulum in terms of the period of its oscillations

$$M_r = \frac{a}{T^2} \sin \alpha, \qquad (1)$$

where $a = I\pi^2$; I is the pendulum's moment of inertia with respect to the knife-edge axis of oscillation; α is the rotation angle of the pendulum; T is the oscillation period of the physical pendulum.

From (1) it is possible to determine sensitivity n of the equipment and the multiplying factor F of the scale

$$n = \frac{\alpha}{M} \approx \frac{T^2}{a}; \qquad (2) \qquad F = \frac{1}{n} \approx \frac{a}{T^2} \qquad (3)$$

(which hold for small angles).

The undesirable unbalance moment of the system being measured on the device is equal to:

$$M_u = F\beta \qquad (4)$$

where β is the deflection angle (in minutes) of the device under the effect of moment M_u.

In order to determine the undesirable moments it is in practice unnecessary to know the value of g; it is sufficient to establish the sensitivity of the equipment and the multiplying factor for its scale.

Having determined the oscillation period T of the equipment, it should be subjected to an additional known moment M_w by means of a load placed on horizontal rod 8 (Fig. 1), at a known distance from the axis of oscillations. Thus the instrument can be deflected from its balance position and sensitivity determined as the ratio of the deflection angle of α_1 to the additional moment $n = \alpha_1 / M_w$. By determining n for various periods T it is possible to find the relationship $n = f(T)$. Having obtained these data it is possible to select the required sensitivity for the measuring device, and hence the multiplying factor for its scale.

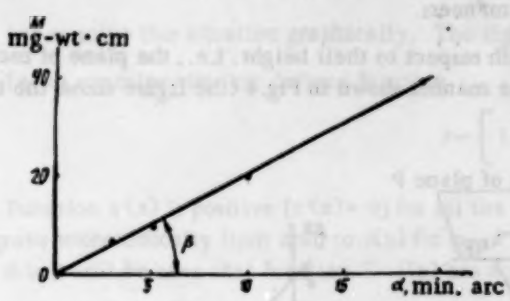


Fig. 2

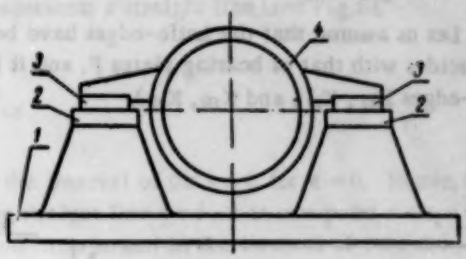


Fig. 3

Tests have shown (Fig.2) that the slope angle tangent of the characteristic curve of $M = f(\alpha)$ which determines the multiplying factor of the scale for a given oscillation period and weight of the moving part is virtually constant to fractions of a percent, mg-wt · cm/ min · arc

$$\operatorname{tg}\beta = \mu \approx \text{const.} \qquad (4a)$$

The double knife-edge device for measuring moments (Fig.3) consists of a cast iron frame 1, two steel bearing plates 2, two knife-edges 3 mounted on holder 4, which makes it possible to displace the knife-edges. The factor which determines the quality of this arrangement and characterizes its sensitivity and stability of readings is the relative position of the knife-edges and the bearing plates. The position of the bearing plates must coincide with an accuracy of 0.1 μ and they must have a grade 14 surface finish. It is only possible to obtain such a highly accurate adjustment of the plates by lapping them in common with a single lapping plate. The frame is first artificially aged in order to stabilize all its bearing dimensions.

The double knife-edge device should be provided, like the single knife-edge device, with a special spindle and weight whose displacement would vary the center of gravity of the moving part and thus control the sensitivity of the instrument.

In this case the readings should be obtained and the multiplying factor of the scale determined in the same manner as for the single knife-edge instrument.

In order to make the equipment sufficiently accurate for measuring moments of the order of 0.5 - 1 mg-wt · cm/ min · arc with the moving part weighing up to 2-3 kg it is necessary to obtain a colinearity of the two knife-edges with an accuracy of 0.033 min of the arc and an alignment of their knife-edges with an accuracy up to $h = 0.2\text{-}0.3\ \mu$.

The absence of any methods for checking or adjusting knife-edges with respect to their bearing plates has prevented the wide application of these bearings for precision measurements.

E. B. Levental' has suggested a very simple and accurate method of checking the alignment of two knife edges. The method is based on assuming a precise coincidence of the two planes on which the knife-edges rest. According to this method the precision adjustment and placing of the knife-edges is attained by lapping until the light beams obtained by illuminating the contact surfaces are converted into minute points of light in the shape of a string of beads.

Such a picture indicates a lack of coincidence between the knife-edge and a plane amounting to h = 0.2-0.3 μ. For this purpose holder 4 (Fig.3) with the knife-edges fixed to it is placed in frame 1 and illuminated by a powerful source of light whose rays are directed to contact surfaces between the prisms and the bearing plates.

Several errors in positioning two knife-edges with respect to their plates are possible: 1) the knife-edges are incorrectly placed with respect to their height or angle, although correctly aligned in their plan view; 2) the knife-edges are incorrectly aligned in the plan view although correctly placed with respect to height; 3) the knife-edges are incorrectly placed with respect to height and in their plan view.

The presence of one of the above defects leads to a large moment of stability in the bearings and a rapid decay in oscillations.

A double knife-edge equipment adjusted by the above method has a sensitivity which is almost as great as that of a single knife-edge equipment. If we assume that the value of h independently of its causes, i.e., irrespective of the fact of whether it was produced by a lack of alignment of the bearing plate planes or that of the knife-edges, does not exceed 0.2-0.3 μ, the reduction in the sensitivity of a double knife-edge equipment as compared with a single knife-edge equipment can be determined in the following manner:

Let us assume that the knife-edges have been aligned with respect to their height, i.e., the plane of rectangle S coincides with that of bearing plates P, and it is placed in the manner shown in Fig.4 (the figure shows the traces of knife-edges K_{1L}, K_{2L}, and K_{1R}, K_{2R}).

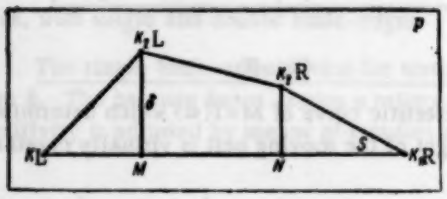


Fig. 4

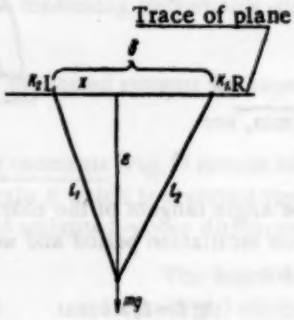


Fig. 5

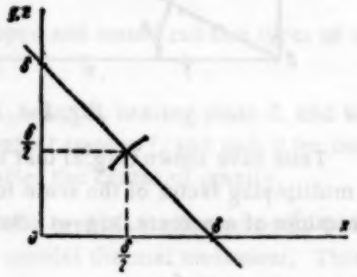


Fig. 6

In order to obtain a balance position of the holder, the projection of its center of gravity onto plane P must not protude outside the contour of rectangle S, otherwide wht moment of gravity will turn plane S with respect to plane P.

Let us now make an assumption which holds in practice, that the projection of the center of gravity of the moving part lies inside trapezium $MK_{2L}K_{2R}N$. Let us denote side MK_{2L} of the trapezium by δ. Full oscillations period T of the physical pendulum will consist of two half-periods with respect to the axes $K_{1L}K_{1R}$ and $K_{2L}K_{2R}$ (to be more precise with respect to an axis parallel to $K_{1L}K_{1R}$ and passing through point K_{2L} – see Fig.5)

$$T = \frac{T_1}{2} + \frac{T_2}{2} = \frac{k_1}{\sqrt{l_1}} + \frac{k_2}{\sqrt{l_2}}, \tag{5}$$

where

$$k_1 = \pi \sqrt{\frac{I_1}{mg}}; \quad k_2 = \pi \sqrt{\frac{I_2}{mg}};$$

$l_1 = \sqrt{\varepsilon^2 + x^2}$ is the length of the physical pendulum referred to axis $K_{1L}K_{1R}$; $l_2 = \sqrt{\varepsilon^2 + (\delta - x)^2}$ is the length of the physical pendulum referred to axis $K_{2L}K_{2R}$.

We shall now show that the decrease in sensitivity will be at its maximum when the projection of the center of gravity will fall on point K_{2L} or point M (see Fig.4).

If we make an assumption, which is accurate to a high degree, that the moment of inertia of the moving parts with respect to the axes of oscillation is constant, the $k_1 = k_2 = \text{const} = k$.

By inserting l_1 and l_2 into (5) and taking into account the above assumption we have

$$T = k\left[\frac{1}{\sqrt[4]{\varepsilon^2 + x^2}} + \frac{1}{\sqrt[4]{\varepsilon^2 + (\delta - x)^2}}\right] = k\left[(\varepsilon^2 + x^2)^{-1/4} + [\varepsilon^2 + (\delta - x)^2]^{-1/4}\right]. \tag{6}$$

Let us find the extremum of function T with respect to x

$$\frac{dT}{dx} = \frac{1}{2} k \left\{ -x(\varepsilon^2+x^2)^{-3/4} + (\delta-x)[\varepsilon^2 + (\delta-x)^2]^{-3/4} \right\} = 0; \tag{7}$$

$$x(\varepsilon^2+x^2)^{-3/4} = (\delta-x)[\varepsilon^2+(\delta-x)^2]^{-3/4}.$$

It can easily be seen that one of the roots of equation (7) is $x_1 = \delta/2$.

It is also easily seen that this extremum is a maximum, since the insertion of the value of $\delta/2$ into the second derivative makes it negative providing $\varepsilon > \sqrt{3/8}\,\delta$, which always holds.

Hence, function $T = f(x)$ has a maximum at point $x = x_1$, i.e., at this point the decrease in the sensitivity of the equipment is at its minimum. Now we must show that $f(x)$ has but one extremum in the interval of $x \mid 0, \delta \mid$. For this purpose let us rewrite (7) as:

$$[\varepsilon^2 + (\delta-x)^2]^{3/4} \cdot x = [\varepsilon^2+x^2]^{3/4}(\delta-x) \tag{8}$$

or

$$\left[1 + \frac{\delta^2 - 2\delta x}{\varepsilon^2+x^2}\right]^{3/4} \cdot x = \delta - x.$$

Let us solve this equation graphically. The right-hand side represents a straight line (see Fig.6).

Let us examine the first derived function

$$z = \left[1 + \frac{\delta^2 - 2\delta x}{\varepsilon^2+x^2}\right]^{3/4} \cdot x. \tag{8a}$$

Function $z'(x)$ is positive $[z'(x) > 0]$ for all the values of x in the interval of $0 \le x \le \delta$ for $\varepsilon \neq 0$. Hence, function $z(x)$ grows monotonically from zero to $z(x)$ for $x \to \delta$ and crosses the straight line $y = \delta - x$ at one point $x = x_1 = \delta/2$. From this it will be seen that function $T = f(x)$ has a single extremum (maximum) in the interval of $0 \le x \le \delta$.

No. of repeated measurements	Amplitude to the left	Amplitude to the right	Mean position
1	93°	94°40′	93°50′
	93°2′	94°40′	93°51′
	93°5′	94°38′	93°51′
	93°10′	94°35′	93°52′
	93°10′	94°30′	93°50′
	93°15′	94°30′	93°52′
2	93°	94°40′	93°50′
	93°	94°40′	93°50′
	93°5′	94°38′	93°51′
	93°10′	94°35′	93°52′
	93°12′	94°30′	93°51′

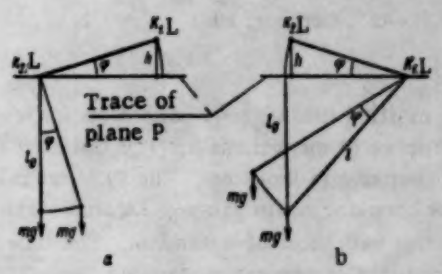


Fig. 7

Thus, an analysis of $T = f(x)$ has shown that a maximum reduction in the sensitivity of the equipment will occur when the projection of the center of gravity falls on point K_{2L} or point M (see Fig.4). In this case the oscillation period T_1 with respect to axis $K_{1L}K_{1R}$ will not equal the oscillation period T_2 with respect to the axis parallel to $K_{1L}K_{1R}$ and passing through point K_{2L}.

Let us examine the case when the projection of the center of gravity falls on point K_{2L} (see Fig. 7). When the pendulum is inclined in a counter-clockwise direction (Fig.7a) its length will equal l_0 (these oscillations will be similar to those of a pendulum with a single knife-edge). When the pendulum is inclined in a clockwise direction (Fig. 7b) its length will equal to

$$l = \sqrt{l_0^2 + \delta^2}, \qquad \text{but} \quad \delta = \frac{h}{\sin\varphi}, \qquad \text{whence} \quad l = \frac{1}{\sin\varphi}\sqrt{h^2 + l_0^2 \sin^2\varphi}. \tag{8b}$$

With an increasing l the oscillations period and hence the sensitivity of the equipment decrease. The maximum decrease in the sensitivity of a double, as compared with a single knife-edge equipment is equal to:

$$\Delta n = n_1 - n_2, \tag{8c}$$

where n_1 is the sensitivity of a single knife-edge equipment; n_2 is the sensitivity of a double knife-edge equipment.

The calculation of Δn made from the test results on the basis of the above formulas has shown that the maximum decrease in sensitivity of a double as compared with a single knife-edge equipment does not exceed 0.05%.

The measurement results for determining the reading stability of a double knife-edge equipment are shown in the table. The knife-edges and bearing plates were made of brand ShKh 15 steel, the knife-edge hardness was HRC = 60, the bearing plate hardness was HRC = 64, the oscillation period of the physical pendulum was T -20 sec, and the operating angle was $\gamma = 120°$.

Conclusions. 1. A single knife-edge equipment provides high sensitivity n = 1.1 -1.67 min · arc/mg-wt · cm with the weight of the moving part exceeding 1 kg, and the measurement error of the movement amounts to 0.0018 g-wt · cm.

2. The method suggested by E. B. Levental' for a double knife-edge equipment provides a high sensitivity n = 0.8 -1.05 min · arc/mg-wt · cm and a stable reading with a considerable load (Q = 3 -6 kg); the measurement error of the moment amounts to 0.002 g-wt · cm.

3. The range of measurements with a multiplying factor F = 1 mg-wt · cm/min · arc amounts to ± 0.15 g-wt · cm.

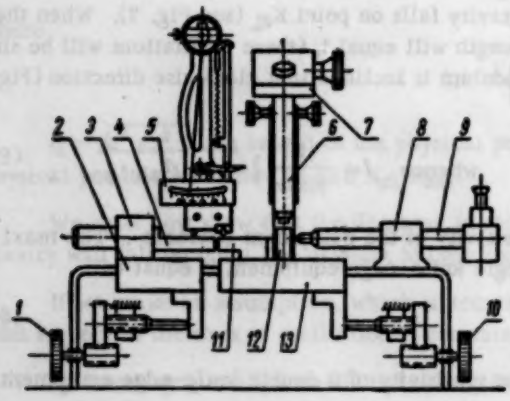
CHECKING STRAIN GAUGES ON THE PKM SET

B. N. Vorontsov

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 24-25, October, 1961

The existing strain-gauge calibrators for testing strain gauges do not meet the requirements of accuracy, range and convenience of measurement. The Gor'kii GKL (State Inspection Laboratory) uses for this purpose the PKM set designed for checking mikrokators. The PKM set is based on the principle of longitudinal comparison which is most suitable for checking strain gauges. Measurements by means of this set amount to comparing the readings of the tested instruments with those of a standard. The tube of interferometer PIU-2, an optimeter or a microscope with an eyepiece micrometer can be use as standard instruments. The possibility of using standard instruments differing in their accuracy and range in conjunction with a PKM set extend the sphere of its application and provide the possibility for testing measuring heads calibrated in 0.1 μ with a range of 2 mm.

The instrument (see figure) has two tables which can be displaced independently from each other in the longitudinal direction. The measuring table 13 with projection 12 is displaced by means of flywheel 10, and the amount of its displacement is read off on microscope 6, 7 or on the optimeter tube 9 fixed in support 8. Stage 2 is displaced by means of flywheel 1.



For checking strain gauges on the PKM set it is necessary to produce bracket 3, holder 4, and stop 11. Bracket 3 is rigidly fixed to stage 2 together with its holder 4, and stop 11 is fixed to the measuring table 13.

The measured strain gauge 5 is placed on the instrument in such a manner that its stationary knife-edge rests against holder 4, and the moving knife-edge against stop 11. The strain gauge is secured in this position by means of a special gripping device with which holder 4 is equipped. It will be seen from the figure that the displacement of measuring table 13 is transmitted through stop 11 to the moving knife-edge of the strain gauge. For checking strain gauges in a horizontal position it is only necessary to release the lock-screw on the stop 11 bush, turn holder 4 through

90°, adjust the strain gauge pointer to the zero position by means of flywheel 1, and proceed with the normal measuring cycle.

It has been demonstrated in practice that testing of strain gauges by means of set PKM exceeds in its accuracy, stability of readings and convenience of operations all the systems of strain-gauge calibrators known to us, and makes it possible to extend the range of its application without any further capital expenditure on its modernization.

It would be very desirable for instrument-manufacturing plants to weigh up the possibility of using this instrument for checking strain gauges and to make the required alterations in the specifications used for their manufacture.

INSTRUMENT FOR MEASURING TENSION IN WIRES

I. G. Grinman and L. P. Pushkarev

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 25-26, October, 1961

The existing contact methods of measuring tension in wires during their drawing have several shortcomings: loops at measuring points, difficulty of measuring at high speeds, possibility of scratching the surface of wires at the place of contact, etc. We have suggested and tested out a contactless method of measuring tension in wires by means of the frequency of their oscillations during drawing.

In order to apply the new method it is necessary to find a mathematical expression for the frequency of oscillations by solving the wave equation of a moving wire. The fundamental frequency of transverse oscillations in the wire is:

$$f=\frac{a}{2l}\left(1-\frac{v^2}{a^2}\right). \qquad (1)$$

where v is the speed of the wire movement (speed of drawing); $a=\sqrt{t/\rho}$ is the speed of propagation of transverse oscillations; l is the length of wire between contact points (drum and drawplate).

If in this formula we neglect quantity v^2 (in practice, normally $v^2 \ll a^2$) and substitute for $a=\sqrt{t/\rho}$ its value where $\rho=\pi d^2\gamma/4$, d is the diameter, γ is the specific gravity of wire, and ρ the mass of a unit length, we shall obtain an expression for the tension in terms of frequency f

$$\sqrt{T}=1{,}83\cdot 10^{-3}\, dl\sqrt{\gamma}\, f. \qquad (2)$$

The value of T from this formula will be obtained in kg-wt, if d is expressed in cm, l in cm, and γ in g/cm³.

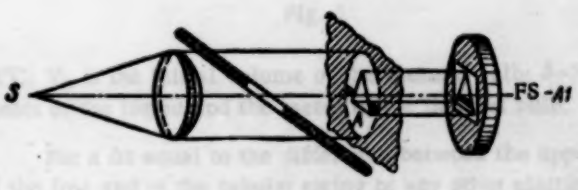


Fig. 1

The instrument consists of a transducer, and of a fruquency-measuring and supply unit. The transducer includes an illuminator, a photovaristor and two preamplifier stages. The instrument itself comprises a supply unit, a frequency-measuring device and an indicating instrument consisting of a 50 μa microameter type M-24.

The instrument's principle of operation. The oscillating wire is lit up by a beam of light from illuminator S (Fig.1). The beam is then passed through a triangular slot A and falls on the sensitive layer of photovaristor FS-A1, which is connected to the first stage of the amplifier. Owing to the triangular shape of the slot the beam of light passing through it is directly proportional to the variation in the position of the wire with respect to the slot. Thus, a sinusoidal vibration of the wire produces a sinusoidal variation in the light flux incident to the photovaristor's sensitive layer. The signal from the photovaristor is amplified and fed

to the transistorized frequency meter. For measuring tension the instrument is provided with a system of three variable resistors connected in an Ayrton shunt circuit across a microammeter (Fig. 2). The shunt resistances for measuring wire tension are set according to the values of $\underline{d}$, $\underline{l}$ and $\sqrt{\gamma}$ for the given wire.

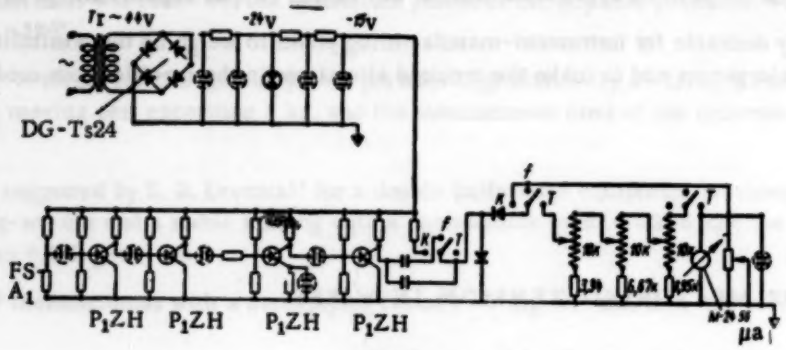


Fig. 2

The shunting effect of each resistor affects the current in the measuring instrument independently of the value of resistances in the remaining shunts. The current flowing through the measuring instrument with all three shunts being operative is proportional to the value of $dl\sqrt{\gamma f}$, i.e., it is proportional to the tension in the wire (a quadratic scale is used for measuring tension). Thus, provision is made for measuring tension in wires of different diameters, lengths and materials.

Owing to the use of transitors the instrument is small and convenient in operation.

In addition to measuring tension in a wire which is being drawn, the instrument is also suitable for measuring tension in threads in the weaving, cable and other industries.

The instrument's technical characteristics are: frequency range of 0 to 200 cps; tension range from 0 to 50 kg-wt for wires 0.5-2.0 mm in diameter, 20-50 cm long and having a specific gravity of 2-9 g/cm^3. The minimum effectively sinusoidal input voltage it can measure amounts to 25 mv, which corresponds to an oscillation amplitude of 0.25 mm of a wire 1 mm in diameter. The instrument operates from 220 v ac mains. The accuracy of the instrument does not depend on the amplitude of the input signal.

THERMOTECHNICAL MEASUREMENTS

TEMPERATURE ERROR OF LIQUID MANOMETRIC THERMOMETERS AND METHODS FOR COMPENSATING IT

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Liquid, especially mercury, manometric thermometers have several advantages compared with vapour and liquid or gas thermometers. They have a smaller thermal inertia, they are more reliable, and they have stable readings in the measured range of -120 to +700°C. Liquid thermometers have a uniform scale. The readings of a correctly designed liquid thermometer do not depend either on atmospheric pressure or the position of the thermal bulb with respect to the elastic sensing element.

The main shortcoming of liquid thermometers consists in their relatively high sensitivity to the variations in the temperature of the air surrounding the elastic sensing element and the long capillary tube of the system.

The temperature error of a manometric thermometer is determined by the parameters of the thermal system employed which converts the measured temperature into displacements of the elastic sensing element's free end.

The simplest thermal system (Fig.1) usually consists of a thermal bulb 1, a connecting capillary tube 2 (long capillary), and an elastic sensing element 3, which comprises springs, a bellows, a diaphragm box, etc. The system is filled (after the air has been exhausted from it) by a thermometric liquid 4 (mercury, toluene, alcohol, xylol, etc.), and is hermetically sealed, for instance, by a tapered threaded connection consisting of coupling 5 and a connecting pipe 6.

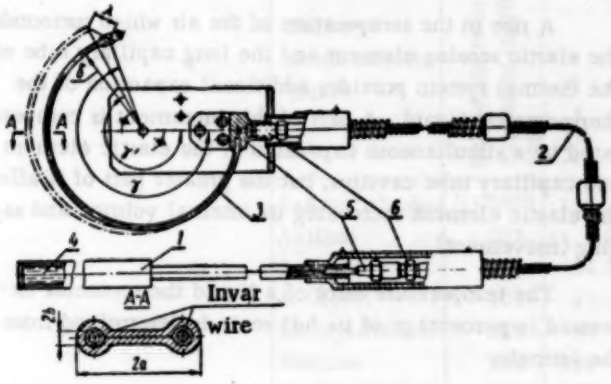

Fig. 1

Temperature variations affect the thermal bulb producing both changes in the volume of the bulb itself and of the liquid in it. The rise in the liquid volume is partly compensated by an increase in the volume of the bulb itself, but the greater part of the additional liquid is pushed out of the bulb along the capillary to the elastic element.

The rise in the liquid volume ΔV_e, which reaches the elastic element owing to a change of temperature in the bulb, is determined by the well-known formula

$$\Delta V_c = \Delta V_l - \Delta V_c = V_c \Delta t (\beta - 3\alpha_c). \quad (1)$$

where ΔV_l and ΔV_b are the increments in the volume of the liquid in the bulb and that of the bulb itself respectively when the measured temperature varies by Δt°C; V_b is the initial volume of the thermal bulb; $\beta - 3\alpha_b$ is the difference in the bulk temperature expansion coefficients of the liquid and the metal of the thermal bulb.

For a Δt equal to the difference between the upper t_2 and lower t_1 temperature limits the normal displacement of the free end of the tubular spring or any other elastic element amounts to λ_p, which corresponds to the temperature range measured on the scale of the manometric thermometer.

In the absence of air bubbles in the thermometer system the whole of the value of $\Delta V_l - \Delta V_b$ is transmitted to the elastic element and hence the sagging of the elastic element will follow the expansion law of the thermometric liquid in the bulb.

Increment ΔV_d in the volume of the diaphragm box can be calculated with sufficient accuracy from the formula:

$$\Delta V_d = F_e \lambda_p. \tag{2}$$

where F_e is the effective area of the diaphragm box.

The increment ΔV_c of the bellows volume is determined from the formula:

$$\Delta V_c = \pi \lambda_p \left(\frac{R_x + R_i}{2} \right)^2. \tag{3}$$

where R_x and R_i are the external and internal radii of the bellows.

Increment ΔV_s of the single-turn tubular manometric spring is calculated from the converted formula [1]

$$\Delta V_s = 0{,}21 \frac{K}{\Gamma} ab\gamma\lambda_p \tag{4}$$

or

$$\Delta V_s = 0{,}21 Kab\rho\,(\gamma - \gamma'). \tag{5}$$

where a is the major cross sectional half-axis; b is the minor cross sectional half-axis (Fig.1); γ is the angle at center of the spring; $\gamma - \gamma'$ is the variation in the angle at center of the spring, i.e., the effective spring unwinding angle; ρ is the spring radius of curvature; K is a coefficient (from Table 1) which only depends on the cross sectional axes ratio of the manometric spring tube; T is a coefficient (from Table 2) which depends on the value of the spring's angle at center.

TABLE 1. Values of Coefficient K with Respect to the Ratio of Axes a/b in the Manometric Tubular Spring Cross Section

$\frac{a}{b}$	1	1,5	2	3	4	5	6	7	8	9	10	∞
K	–	0,113	0,197	0,242	0,262	0,271	0,276	0,283	0,288	0,290	0,291	0,311

TABLE 2. Relation of Coefficient r to the Values of the Angle at Center γ

$\gamma°$	r	$\gamma°$	r
210	4,42	280	5,93
220	4,82	290	6,03
230	5,05	300	6,12
240	5,26	310	6,18
250	5,47	330	6,25
260	5,64	360	6,28
270	5,81	450	6,92

It will be seen from formulas (2)-(5) that the relation between ΔV_e and λ_p is only determined by the geometrical dimensions of the elastic sensing element.

It follows from formulas (1)-(5) that the readings of a liquid thermometer do not depend on the variations in the modulus of elasticity of the system's elastic element due to ambient air temperature changes. This situation has been confirmed experimentally.

A rise in the temperature of the air which surrounds the elastic sensing element and the long capillary tube of the thermal system provides additional expansion of the thermometric liquid. A part of this increment is compensated by a simultaneous expansion of the elastic element and capillary tube cavities, but the greater part of it affects the elastic element increasing its internal volume and sagging (movement).

The temperature error of a liquid thermometer expressed in percentage of its full scale is determined from the formula:

$$\delta = \frac{\Delta\lambda \cdot 100}{\lambda_p} = \frac{\Delta V_1 \cdot 100}{\Delta V_e}, \tag{6}$$

where $\Delta\lambda$ is the sagging (movement) of the elastic element due to the increment ΔV_1.

$$\Delta V_1 = (V_k + V_e + 1{,}25\Delta V_e)(\beta - 3\alpha)\Delta t_1. \tag{7}$$

where V_k and V_e are the internal volumes of the system's capillary tube and elastic element respectively; $1{,}25\Delta V_e$ is the increment of the initial elastic sensing element volume (normally equal to 0,25 λ_p) up to a value corresponding to an effective sagging produced by a full-scale variation of the bulb temperature; Δt_1 is the temperature variation of the air surrounding the capillary tube and the elastic element; $\beta - 3\alpha$ is the difference in the bulk temperature expansion coefficient of the capillary tube and the elastic element.

By inserting the values of ΔV_1 and ΔV_e into (6) we obtain (in percent):

$$\delta = \frac{(V_\kappa + V_e + 1{,}25\Delta V_e)\,(\beta - 3\alpha)\,\Delta t_1 \cdot 100}{V_c\,\Delta t\,(\beta - 3\alpha_c)}. \quad (8)$$

The value of V_b is determined from (1), hence we can write:

$$\delta = \frac{\Delta t_1\,(V_\kappa + V_e + 1{,}25\Delta V_e)\,(\beta - 3\alpha)\cdot 100}{\Delta V_e}. \quad (9)$$

The maximum temperature deviation Δt_1 from the normal +20°C (the temperature at which the instrument was calibrated) has been established by GOST (All-Union State Standard) 8624-57 for manometric thermometers at 40°C.

Hence (9) will assume in a general form the following value:

a) for a temperature error calculated at the upper temperature measuring limit

$$\delta = W\,\frac{(V_\kappa + V_e + 1{,}25\Delta V_e)}{\Delta V_e}\ \%; \quad (10)$$

b) for the same error calculated at the lower temperature measuring limit

$$\delta = W\,\frac{(V_\kappa + V_e + 0.25\Delta V_e)}{\Delta V_e}\ \%. \quad (11)$$

where $W = (\beta - 3\alpha)\Delta t_1 \cdot 100$.

The values of W for various thermometric liquids at $\Delta t_1 = 1$°C and $\Delta t_1 = 40$°C are given in Table 3.

TABLE 3. Thermometric Liquids, Their Physical Properties and Data of Thermal Systems.

Name of thermometric liquid	Bulk temperature expansion coefficient	M.p., °C	B.p., °C	Value of coefficient W		
				Critical temp, °C	for $\Delta t_1 = 1$°C	for $\Delta t_1 = 40$°C
1-Amyl alcohol	0.00093	-117	+131.5	+ 307	0.089	3.560
Aniline	085	- 6.2	+184.2	+ 426	0.081	3.240
Acetone	131	- 94.3	+ 56.7	+ 235	0.129	5.160
M-Xylol	101	- 49.3	+138.5	+ 350	0.097	3.900
Methyl alcohol	122	- 97	+ 64.7	+ 240	0.118	4.720
Pentane	160	-160	+ 27.9	+ 201	0.156	6.240
Propyl alcohol	095	-127	+ 96	+ 260	0.091	3.640
Mercury	0182	- 38.87	+356.7	+1470	0.0148	0.592
Toluol	109	- 95.1	+110.8	+ 320	0.105	4.200
Chlorobenzene	108	- 45.5	+132	+ 261	0.104	4.160
Ethyl alcohol	110	-114	+ 78.3	+ 243	0.106	4.240
Ethyl bromide	137	-125	+ 38	+ 231	0.133	5.320
Ethyl ether	163	-116.3	+ 34.6	+ 194	0.159	6.360
Amyl alcohol	093	-129	+ 97	—	0.089	3.650

From (10) and (11) it follows that:

a) in order to reduce temperature errors in liquid thermometers it is advisable to use thermometric liquids with a minimum and bulbs with a maximum bulk temperature expansion coefficient;

b) The properties of mercury make it most suitable for use in such thermometers and provide a reduction of the temperature error by a factor of 5 - 7 as compared with other thermometric liquids;

c) the reduction of the temperature error of non-mercury thermometers is affected but little by the choice of the bulb material, since the bulk temperature expansion coefficient, for instance, of xylol (0.00101) is 30.5 times greater than the coefficient of steel(0.000036)and 20.4 times larger than brass (0.000054). The values of the bulk coefficients of mercury and steel are considerably closer (they differ by a factor of 5), thus tending under the same conditions to reduce the temperature error to 0.4% of the full-scale deflection;

d) for a condition when $V_k \approx 0$ and $V_e \approx 0$, which occurs in thermal systems without a capillary tube or with a tube which has an exceedingly small internal volume and with an elastic element which has no initial volume, the temperature errors of non-compensated liquid thermometers cannot be reduced below 1.25 W providing the elastic sensing element of the system has a displacement (effective movement) and changes, therefore, its internal volume.

These minimum possible values of temperature errors are being approached owing, among other things, to the new channeled cross section of manometric tubular springs [2] (Fig.1, cross section A - A).

The distinctive characteristic of this type of manometric tube cross section consists in the middle squashed section which has no gap between the walls. Two drop-shaped channels are placed symmetrically along the sides of the manometric tube. They provide an optimum ratio of the side rim radius to the wall thickness, thus raising the mechanical quality of the tube. Such a tube cross section provides an optimum ratio between the initial internal volume V_e and its increment ΔV_e for the effective movement of the spring. This is due to the expansion of the middle portion of the cross section, thus providing, with the other conditions remaining the same, a rise in the value of ΔV_e for a constant V_e.

The temperature error is also lowered by placing an invar wire inside the tube channels.

A further reduction and compensation of the temperature error in liquid thermometers can be attained by means of various compensating devices.

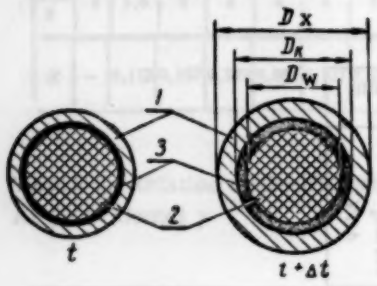

Fig. 2. Cross section of a capillary tube with an invar wire.

Bimetallic compensators. Bimetallic strips are often used as temperature error compensators in liquid manometric thermometers which have relatively short capillary tubes of the order of 3 - 4 m. A bent bimetallic strip is added to the kinematic system of the thermometer, usually in its drive, and is calculated so that its bending compensates for the displacement $\Delta\lambda_e$ of the elastic element's free end due to the variation in the surrounding air temperature:

$$\lambda_m = \Delta\lambda_e = \lambda_p \frac{\Delta t_1 (V_\kappa + Ve + 0{,}25\Delta Ve)(\beta - 3\alpha)}{\Delta V_e}, \qquad (12)$$

where λ_m is the displacement of the end of the bimetallic strip.

With variations in the temperature of the liquid which has a volume of $V_k + V_e + 0.25\ V_e$, the value of λ_p does not increase but is displaced by $\Delta\lambda_e$ along the axis Δt as shown in the graph for $\lambda_p = f(\Delta t)$, which is equivalent to a displacement of the thermometer pointer with respect to its scale. In this instance an appropriate adjustment of the bimetallic element position will provide almost a complete compensation of the temperature error. For this purpose it is possible successfully to use welded bimetallic tubular springs [3].

The variable temperature error due to the increase in the elastic element volume V_e by an amount of ΔV_e with a temperature variation of Δt can be greatly reduced if a bimetallic compensator of a suitable design is used for this purpose.

An essential drawback of bimetallic compensators consists in the fact that they compensate effectively only the temperature error due to changes in the temperature of the elastic element.

Compensation by means of invar inserts. The remoteness of thermometer indications can be raised by means of invar wire inserted into the capillary tubes. Wire 2 inserted in capillary tube 1 (Fig.2) is provided with such a diameter that the rise in the liquid volume 3 due to temperature changes of the capillary tube is partly or almost completely compensated by an increase in the anular cavity formed between the capillary tube and the wire.

Let us denote by β_l, β_w, and β_k the bulk temperature expansion coefficients of the liquid, the wire and the capillary tube respectively, and by V_k and V_w the total internal volume of the capillary tube and the wire respectively. Assuming that the bulk temperature expansion coefficients remain constant for any temperature Δt_1 it is possible to write

$$\beta_l V_\kappa \Delta t_1 - \beta_l V_w \Delta t_1 = \beta_w V_\kappa \Delta t_1 - \beta_w V_n \Delta t_1. \quad (13)$$

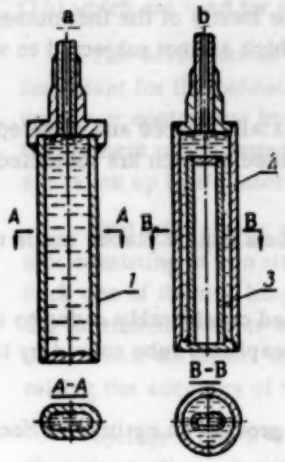

Fig. 3

Here the left-hand side of the equation represents an increase in the volume of liquid between the wire and the capillary tube, and the right-hand side an increase in the volume of the anular spacing between the capillary wall and the wire due to their expansion with temperature.

By transforming (13) we obtain

$$\frac{V_w}{V_\kappa} = \frac{\beta_l - \beta_\kappa}{\beta_l - \beta_w}. \quad (14)$$

Substituting the ratio of V_w/V_k by that of D_w/D_k we have

$$\frac{D_w}{D_\kappa} = \sqrt{\frac{\beta_l - \beta_\kappa}{\beta_l - \beta_w}}. \quad (15)$$

It will be seen from (15) that for effective compensation the bulk temperature coefficients of the capillary tube and the wire should differ from each other as much as possible.

The most suitable material for the wire consists of invar or steel with a minimum bulk temperature expansion coefficient.

In this case $\beta_w \approx 0$ and hence (15) will become:

$$\frac{D_w}{D_\kappa} = \sqrt{1 - \frac{\beta_\kappa}{\beta_l}} = K_3. \quad (16)$$

Of the various thermometric liquids used mercury possesses the smallest bulk temperature expansion coefficient (Table 3).

Materials from which capillary tubes are normally made have the following bulk temperature expansion coefficients: for stainless steel brand $1Kh_{18}N_9T$ it is $\beta_k = 48 \cdot 10^{-6}$ deg^{-1}; for carbon steel or iron it is $\beta_k = 33\text{-}36 \cdot 10^{-6}$ deg^{-1}; for copper it is $\beta_k = 50 \cdot 10^{-6}$ deg^{-1}; for brass $\beta_k = 56.4\text{-}60 \cdot 10^{-6}$ deg^{-1}.

On this basis we find that the coefficient for mercury thermometers with a stainless steel capillary tube is equal to $K_3 = 0.90$, and for thermometers in brass capillary tubes filled with a liquid which has a $\beta_l = 85 \cdot 10^{-5}$ deg^{-1} it is equal to $K_3 = 0.962$.

For a $\beta_l = 109 \cdot 10^{-5}$ deg^{-1} (toluol) or $\beta_l = 101 \cdot 10^{-5}$ deg^{-1} (xylol) and for $\beta_k = 60 \cdot 10^{-6}$ deg^{-1} the value of K_3 is equal to 0.975 and 0.970 respectively.

Let us note that for $K_3 \geq 0.97$ the difference $D_k - D_w$ changes from 0.02 to 0.3 mm with a rising D_k and assumes a value of 0.3 mm which is still small enough to be permissible when $D_k = 10$ mm.

For values of K_3 exceeding 0.97 the degree of compensation is affected to a considerable extent by the deviations of the capillary tube and invar insert dimensions from their calculated values.

Keeping this in mind, as well as the rapid growth of hydraulic resistance in the capillary tube with a reduction in its anular gap (according to Poiseuille's formula, the resistance of a capillary tube rises in inverse proportion to the fourth power of its radius and in direct proportion to its length and the viscosity of its liquid), it becomes in practice only possible to compensate by inserting an invar wire into the capillary tube if coefficient K_3 does not exceed 0.86-0.92 for remotely reading thermometers with a flexible capillary tube, and not exceeding 0.97 for thermometers which have a direct connection between the bulb and the indicator.

Thermal bulb with a varying volume. It follows from (9) that the use of themal bulbs with a large linear expansion coefficient tends to reduce the temperature error of the liquid thermometers with which they are used. However, since the value of 3α as compared with coefficient β is normally small, especially in non-mercury thermal systems, the temperature error in the latter case is not reduced substantially. The temperature error can be reduced substantially by means of a similar relationship if the thermal system uses bulbs whose internal volume changes considerably with temperature [4].

Fig.3 shows various designs for thermal bulbs with a variable volume.

Bulb a made in the form of manometric tube 1 of an oval cross section reduces the inertia of the thermometer. A thermometer with such a bulb can be used for measuring the temperature of media which are not subjected to varying pressures.

Bulb b is made in the form of a round tube 2 whose internal cavity contains a coaxially placed and soldered or welded-in manometric tube 3. Such a bulb can be used for measuring temperatures of media which are subjected to changing pressures.

Bellows hermetically sealed at both ends or a diaphragm box of a required stiffness can be placed inside the round tube of the thermal bulb.

When such bulbs are used with liquid thermometers the temperature error is reduced considerably owing to the fact that an increase in the thermometric liquid volume in the elastic element and the capillary tube caused by temperature changes affect not only the elastic element but also the thermal bulb.

The volume of the liquid in the bulb is then increased correspondingly in order to provide an optimum effective displacement of the elastic element.

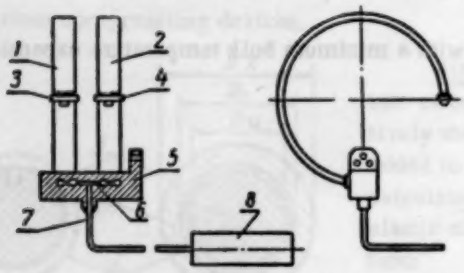

Fig. 4

In this connection the internal volume of the bulb with a variable volume is calculated from the formula

$$V_b = \frac{\Delta V_e + \Delta V_i}{\Delta t(\beta - 3\alpha)}, \tag{17}$$

where ΔV_e and ΔV_i are the volume increments of the system's elastic element and the bulb insert respectively.

For a constant bulb temperature the liquid volume increment ΔV_i due to temperature variations of the air surrounding the capillary tube and the elastic element are determined from (7) and divide in inverse proportion to the stiffness of the elastic element and bulb insert:

$$\frac{C_i F_e}{F_c C_e} = \frac{\Delta V_{1e}}{\Delta V_{1i}}, \tag{18}$$

where C_i is the stiffness with respect to pressure of the bulb insert; C_e is the stiffness with respect to pressure of the elastic element; ΔV_{1e} and ΔV_{1i} are the volume increments of the elastic element and the bulb insert respectively due to a temperature variation of Δt_1; F_e and F_i are the effective areas of the elastic element and the bulb insert respectively.

In the above case $\Delta V_1 = \Delta V_{1i} + \Delta V_{1e}$. Hence

$$\frac{C_i F_e}{C_e F_i} = \frac{\Delta V_{1e}}{\Delta V_1 - \Delta V_{1e}}. \tag{19}$$

The temperature error expressed in percentage of a liquid thermometer full scale is determined in this case from the relationship:

$$\delta = \frac{\Delta\lambda \cdot 100}{\lambda_p} = \frac{\Delta V_{1e} 100}{\Delta V_e}. \tag{20}$$

From (11) and (19) we obtain:

$$\delta = \frac{C_c F_e}{F_c C_e + C_c F_e} \cdot \frac{W(V_\kappa + V_e + 1{,}25\Delta V)}{\Delta V_e} \%. \quad (21)$$

By analyzing (21) we arrive at the conclusion that the temperature error of a liquid thermometer with a varying volume bulb decreases in direct proportion to the reduction of stiffness C_l of the bulb elastic insert and the effective area of the elastic sensing element. With a rising value of C_l and F_e and a constant value of C_e and F_l the ratio $C_l F_e/(F_l C_e + C_l F_e)$ tends to 1, the value of $\Delta V \to \Delta V_1$, and the temperature error δ is then determined from (11) or (10) which are used for thermal systems without an elastic insert in the bulb.

The development of thermal bulb designs with a varying volume on their basis of liquid thermometers is important for the production of compensated transducers with a pneumatic or electric transmission of signals to secondary or controlling instruments. The distinctive characteristic of an instrument of such a design consists in the elastic element of the instrument retaining its initial volume, since all the liquid volume increments in the thermal bulb are taken up by its insert.

Unit with elastic sensing elements operating in parallel. Fig.4 shows a schematic of a thermal system with a unit consisting of two single-turn tubular springs 1 and 2 fitted at their free ends with tips 3 and 4 by means of which each one of them is hinged to an independent kinematic system of a thermometer. For instance, one spring displaces the instrument pointer with respect to its scale, and the other connects or disconnects an electrical contact system. This avoids the effect of one kinematic system on the other, and reduces the loading of the elastic elements, thus raising the accuracy of the thermometer reading.

Springs 1 and 2 are fixed to block 5 in which their cavities are interconnected by channel 6 and connected through capillary pipe 7 to the thermal bulb 8.

The internal volume of the bulb V_b is in this case calculated from formula

$$V_b = \frac{\Delta V_{1e} + \Delta V_{2e}}{\Delta t(\beta - 3\alpha)}. \quad (22)$$

The rise of the liquid volume in the capillary tube due to temperature variations ΔV_k in this case provides sagging of springs inversely proportional to their stiffness. If the springs are identical the value of ΔV_k is distributed between them equally.

Thus, the addition of elastic elements to the system tends to reduce the temperature error of the thermometer [5, 6].

Temperature error compensation in parallel reversible thermal systems. With a capillary tube exceeding 10 m in length compensation is achieved by means of a second thermal system which is laid parallel to the first but has no thermal bulb. The elastic element of the compensating system is connected in the kinematic circuit in such a manner that its sagging (movement) is in the opposite direction to that of the main system's elastic element. The elements of the compensating and main systems (capillary tubes, springs and connections) are made identical to each other with respect to their dimensions and filling.

At first sight one would expect a complete compensation of the temperature error providing the free ends of the elastic elements of the main and compensating systems are displaced equally by the ambient temperature vibrations. However, the expected effect of a complete temperature error compensation cannot be attained.

On the basis of a complete compensation the temperature errors of the main and compensating thermal systems must be equal to each other: $\delta_m = \delta_c$.

By equating the temperature errors of the main and compensating systems on the basis of (11) we obtain after certain operations:

$$\frac{V_\kappa + V_e + 0.25\Delta V_{1e}}{\Delta V_{1e}} = \frac{V_{\kappa 2} + V_{2e} + 0.25\Delta V_{2e}}{\Delta V_{2e}}. \quad (23)$$

It will be seen from (23) that in order to obtain a fully compensated liquid thermal system it is necessary to

to have equal internal volumes of springs and of volume increments as well as of the internal volume of capillary tubes. In practice it is impossible to attain this condition owing to the deviations of the capillary tubes and springs from their nominal dimensions.

Moreover, the internal volume of the main system's tubular spring varies in the course of operation independently of the compensating thermal system operation. Hence, it is impossible to achieve the expected full compensation of the temperature error. On the other hand the use of such compensating devices makes the thermal system as a whole more complicated and expensive.

LITERATURE CITED

1. V. I. Feodos'ev, Elastic Elements in Precision Instrument-Making [in Russian] (Oborongiz, 1949).
2. I. A. Sychev, Author's Certificate No. 96553 dated March 20, 1951.
3. I. A. Sychev, Author's Certificate No. 117863 dated June 10, 1957.
4. I. A. Sychev, Author's Certificate No. 105474 dated September 28, 1954.
5. I. A. Sychev, Author's Certificate No. 108104 dated November 26, 1956.
6. I. A. Sychev, Author's Certificate No. 117761 dated November 26, 1956.

THERMOELECTRIC PROPERTIES OF THERMOCOUPLES WITH HIGH-MELTING SOLID ELECTRODES

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Zirconium boride and carbide (ZrC and ZrB_2) are solid, high-melting compounds which possess with a relatively high stability a low electrical resistance, good thermal conductivity and a moderate coefficient of thermal expansion (see Table 1 for certain physical properties of ZrC and ZrB_2). The physical properties of these compounds combine fortunately to give high resistance to various corrosive media. Thus, they resist the action of hydrogen, carbon monoxide, their mixtures, a mixture of carbon monoxide and nitrogen, fused ferrous and nonferrous metals, including steels, cast iron, and certain molten salts and slags [1]. The stability of zirconium is shown in [2] when used at high temperatures in the presence of carbon. Zirconium boride and carbide virtually do not combine with each other [3].

TABLE 1

Physical properties	ZrC	ZrB_2
Density, g/cm³	6.9	5.82
Micro-hardness, kg-wt/mm²	2830	2250
Compression strength, kg-wt/mm²	170	160
Bending strength, kg-wt/mm²	29	39
Melting temperature, °C	3735	3040
Thermal conductivity, cal/cm·sec·deg	0.049	0.055
Coefficient of thermal expansion, deg⁻¹	$6.73 \cdot 10^{-6}$	$6.83 \cdot 10^{-6}$
Resistivity, μohm·cm	57.4	16.6

TABLE 2

Electrode material	Temp., °C	Medium	Change in weight of electrodes (mg/cm²) after exposure		Variation in the thermal emf of electrodes coupled with Pt (μv) at 100 °C after exposure	
			10 hr	20 hr	10 hr	20 hr
ZrB_2	2000	H_2	−0,004	−0,009	30–40	30–40
		$CO+H_2$	0	0	30–40	30–40
ZrC (№ 1)	2350	H_2	−0,04	−0,06	24–30	28–30
		$CO+H_2$	+0,06	+0,09	30–35	35–45
ZrC (№ 2)	2350	H_2	0	0	15–20	15–20
		$CO+H_2$	+0,003	+0,005	15–20	15–20

The above properties provided promising possibilities for the use of zirconium boride and carbide for electrodes of high-temperature thermocouples [4]. The stability of these materials under the effect of various gases or metals

in fusion together with the lack of reaction between them should provide a high stability of reading for thermocouples made of these compounds.

In this work we investigated the thermoelectric properties of such a thermocouple made according to the technology described in [4, 5], as well as the behaviour of its electrodes in various media. The zirconium boride used had a virtually stochiometric composition but with an admixture of about 0.4% of free carbon. The zirconium carbide used consisted of Zr 85.1%, C_{com} 12.8%, C_{free} 1.62%, Fe 0.05% (batch No. 1), and the same zirconium carbide after flotation of the free carbon by means of a 2% solution of soap (batch No. 2). Thermoelectrodes were made of these materials and their thermal emf measured in a couple with platinum after an exposure for 10 and 20 hours at a maximum operating temperature in medias of H_2 and $CO + H_2$. The results of these tests are shown in Table 2.

It will be seen from these data that the presence of free carbon has a decisive effect on the stability of the thermal emf of zirconium carbide; moreover, this effect rises with increasing exposure, especially in a gas medium containing CO.

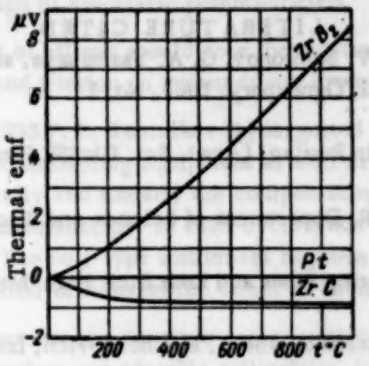

Fig. 1

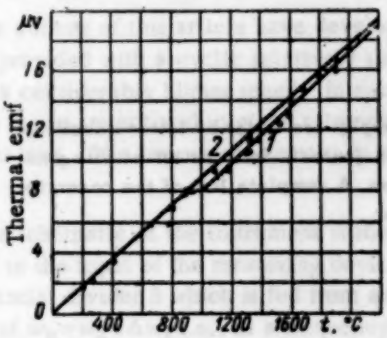

Fig. 3

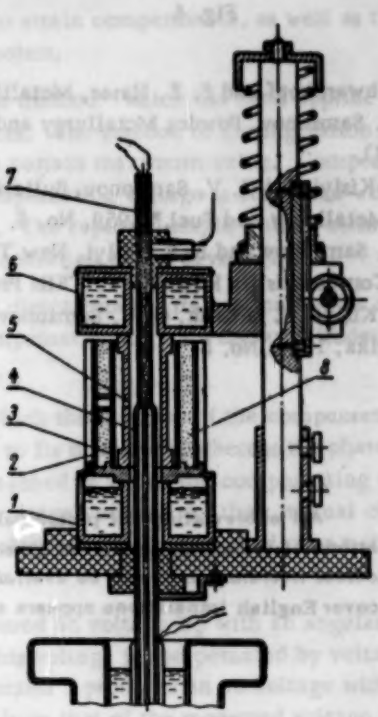

Fig. 2

The relation between temperature and the thermal emf of zirconium boride and carbide (No. 2) was tested on electrode samples 6 mm in diameter and 500 mm long. Their emfs were measured in a couple with platinum. A platinorhodium-platinum thermocouple was used as a reference. The relation between temperature and the thermal emf thus obtained is shown in Fig. 1, which indicates that a thermocouple with electrodes made of ZrC - ZrB_2 should have a virtually linear temperature characteristic (~8.7 μv/deg). The thermocouples were calibrated in the range of 20-1200°C against a reference thermocouple, and in the range of 800-2000°C against an optical pyrometer OPPIR-09. Calibrations were carried out on a set with a graphite heater, shown in Fig. 2. Two water-cooled copper contacts 1,6, grip a graphite heater 5, which is surrounded by two graphite screens 2,3, with graphite grit 8 packed between them. The calibrated 4 and reference 7 thermocouples are fixed in such a manner that their operating junctions remain in contact through a graphite anular packing and are placed in the center of the heater opposite an opening for measuring temperature by means of an optical pyrometer. The calibrated thermocouple is in direct contact with the graphite ring, but the reference thermocouple is separated from it by an alundum nipple. The use of a packing ring reduces the temperature difference between the junctions of the calibrated and reference thermocouples. By means of this equipment it is possible to calibrate up to 300 °C. In order to prevent oxidation at high temperatures argon is pumped into the equipment.

Calibration results are shown in Fig. 3 and reveal a linear relation between temperature and the thermal emf of thermocouple ZrC -ZrB_2 up to 2000°C (in this Figure calibration curve 1 was obtained by means of an optical pyrometer, curve 2 by means of a reference thermcouple with the range between 1000 and 2000°C being extrapolated).

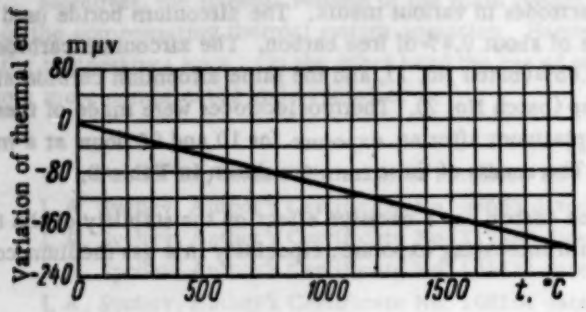

Fig. 4

The stability of the calibrated thermocouple characteristic was tested by the technique described in [6] by exposing the thermocouple for 25 hours at 1800°C to a hydrogen atmosphere. The change in the thermocouple's emf established by a second calibration in the above set at temperatures of 500, 1000, 1500, and 2000°C is shown in Fig. 4, from which it will be seen that this variation does not exceed 25 ° at 2000°C (i.e., ~1%).

LITERATURE CITED

1. G. V. Samsonov, G. A. Yasinskaya, and Shou-wei T'ai, Ogneupory, 1960, No. 1.
2. P. Schwarzkopf and F. Z. Haser, Metallkunde, 1953, No. 44.
3. G. V. Samsonov, Powder Metallurgy and Strength of Materials [in Russian] (Acad. Sci. UkrSSR Press, Kiev, 1959, No. 7).
4. P. S. Kislyi and G. V. Samsonov, Bulletin of the Acad. Sci. USSR, Department of Science and Technology, series on "Metallurgy and Fuel," 1959, No. 6.
5. G. V. Samsonov and B. S. Kislyi, New Technology in Manufacturing Pipes and Rods from High-Melting Metals and Compounds [in Russian] (TsITÉIN Press, Moscow, 1959).
6. P. S. Kislyi, V. I. Lakh, G. V. Samsonov, B. I. Stadnyk, R. F. Kharenko, and A. B. Chekhovich, Izmeritel'naya tekhnika, 1961, No. 5.

All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

ELECTRICAL MEASUREMENTS

DYNAMIC AC POTENTIOMETER

T. M. Aliev and V. P. Stepanov

Translated from Izmeritel'naya Teknika, No. 10,
pp. 34-39, October, 1961

The compensation method is being widely used in electrical measurements. However, in spite of its many advantages, the compensation method, as applied at present, has certain drawbacks which are particularly noticeable in the design of automatic potentiometers.

First of all one should note the relatively long time required to attain compensation, as well as the effect of backlash and friction on measurement errors in automatic potentiometers.

In 1933 F. E. Temnikov [1] suggested a dynamic compensation method* which has been applied to measuring and remote measuring equipment as well as automatic control devices. The essence of the suggestion consists in varying cyclically and linearly the compensating voltage from zero to a certain maximum value. Compensation is attained only instantaneously in each cycle when the constantly rising compensating voltage is compared with the measured voltage. The null-type instrument registers and records this instant. The repeated single-valued estimation of the compensation eliminates the effect of friction and backlash on the operation of the device [2].

At present the dynamic compensation method is only used for direct current, its application for an alternating current involves considerable difficulties, since at the instant of compensation not only the amplitudes but also the phases of the measured and compensating voltages must be equated.

The authors of this article have developed an instrument in which the modulus of the compensating voltage vector is provided with a cyclic relatively slow variation from zero to its maximum, whereas the phase of the vector varies at a considerably higher speed. In each cycle a position is reached in which the compensating voltage vector coincides for an instant within given tolerances with the measured voltage vector, i.e., their mutual compensation is thus attained. The instrument consists in the main of electronic elements and can be used over a wide frequency range.

The schematic of the instrument is shown in Fig. 1. The measured ac voltage U_x with an angular velocity of ω_x is fed to the input of the measuring device (terminals a -a'). This voltage is compensated by voltage U_k obtained from potential divider 3 which is fed from an ac generator 1. Generator 1 produces an ac voltage with an angular velocity of $\omega_k = \omega_x \pm \Delta\omega$, i.e., at a frequency which differs slightly from that of the measured voltage. Hence, the speed of rotation of voltage vector U_k with respect to vector U_x will be determined by the angular velocity $\pm\Delta\omega$. The slider of potential divider 3 is connected to motor 8, thus making the modulus of voltage vector U_k change linearly and periodically from zero to the maximum. A voltage of frequency $\omega_k = \omega_x \pm \Delta\omega$ and a linearly changing amplitude is taken from potential divider 2, which is synchronized with divider 3, to the phase-splitting device 7. Both voltages are fed to amplifiers 6 of the horizontal and vertical deflecting plates of a cathode-ray oscilloscope. The instant of compensation is registered by the null-type instrument 5, which consists of an amplifier, a detector, and a relay element.

If we consider vector U_k to be in a certain rotating system of coordinates formed by the rotating vector U_x, the end of vector U_k will describe an Archimedian spiral (Fig. 2) which starts at the origin of the coordinates and ends at U_k having attained its maximum. The cycle will be completed in one revolution of motor 8.

The difference between the vectors U_x and U_k will vary and at a given moment will become smaller than a predetermined value ΔU. This will occur when the end of vector U_k will be inside a circle whose center is formed by the end of vector U_x and whose radius is equal to ΔU. Let us consider that at this instant compensation has been attained

* The term "dynamic compensation method" or "method of dynamic compensation" should be used conventionally, since the method in itself remains unchanged in its principle. Only the instant of fixing mutual compensation of two voltages in the measuring process is changed (Editor).

in the system. It is obvious that compensation will then be achieved with a certain error whose maximum value is determined by ΔU, i.e., it is predetermined.

The vector of the measured voltage can be shown on a screen of a cathode-ray oscilloscope. At the instant compensation is attained in each cycle the end of the measured vector is indicated by the lighting of a point on the oscilloscope screen. The origin of the coordinates is indicated simultaneously by a lighted point on the screen.

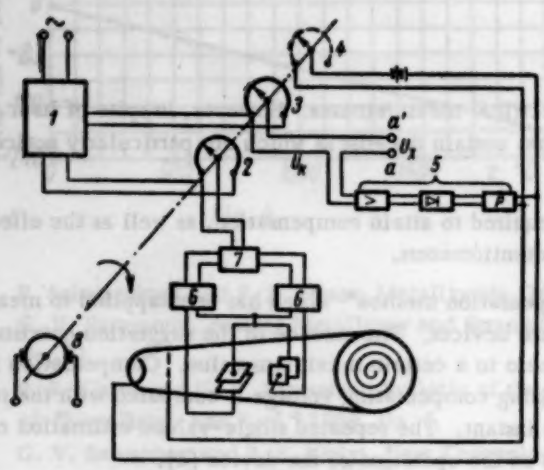

Fig. 1

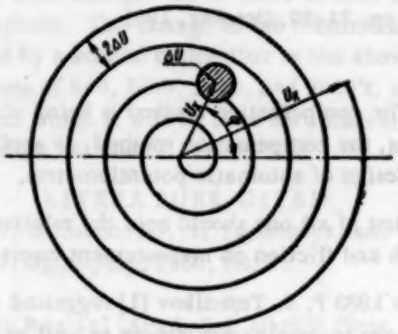

Fig. 2

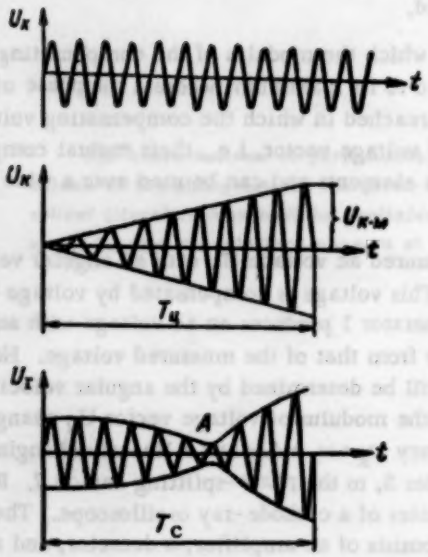

Fig. 3

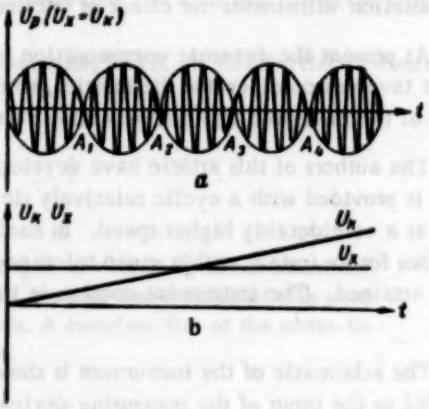

Fig. 4

In order to obtain the image of the vector on the screen the oscillograph beam traces an Archimedian spiral which coincides with that scanned by vector U_k. The beam is blacked out at first by a negative voltage on the grid of the oscilloscope, and it lights up only at the instant compensation is attained when a positive pulse is received from the output of the null-type instrument 5 which registers the compensation.

Let us now examine the basic relationships which determine the choice and design of the null-type instrument.

The resultant voltage U_r which represents the difference between the measured voltage U_x and the compensating voltage U_k appears at the input of the null-type instrument.

The instantaneous value of the resultant voltage is determined by the relation:

$$U_r = U_x \sin \omega_x t - \frac{t}{T_c} U_{k.m} \sin \omega_x t, \qquad (1)$$

where U_x is the amplitude of the measured voltage; U_{km} is the maximum amplitude of the compensating voltage at

the end of the cycle of the compensating voltage vector variations; t is the time measured from the beginning of the cycle, it varies from zero to T_c.

After transformation (1) becomes:

$$U_p = \sqrt{U_x^2 + U_{k.m}^2 \frac{t^2}{T_c^2} - 2U_x U_{k.m} \cos(\omega_x - \omega_k)\, t \cdot \sin(\omega_x t + \operatorname{arctg} m)}, \quad (2)$$

where

$$m = \frac{U_{k.m} \frac{t}{T_c} \sin(\omega_x - \omega_k)\, t}{U_x - U_{k.m} \frac{t}{T_c} \cos(\omega_x - \omega_k)\, t}. \quad (3)$$

Fig.3 shows a graphical representation of voltages U_x, U_k, and U_r during one cycle T_c.

The resultant voltage envelope is obviously represented by the equation

$$U_r = \sqrt{U_x^2 + U_{k.m}^2 \frac{t^2}{T_c^2} - 2U_x U_{k.m} \frac{t}{T_c} \cos(\omega_x - \omega_k)t}. \quad (4)$$

Examination of Fig.3 will show that the instantaneous values of voltage U_r will repeatedly pass through zero during one cycle; however, the null-type instrument must only register the value corresponding to point A, i.e., corresponding to the minimum ordinate of the envelope. This will correspond to the passage of the end of the compensating voltage vector through the shaded circle (Fig.2), i.e., to the compensated condition. In order to provide the grid of the cathode-ray tube with a positive pulse at the instant corresponding to point A (Fig.3), the input of the null-type instrument is provided with a detecting element. This element is followed by a relay (trigger system) which operates at the instant when the voltage impressed on its input becomes smaller than a certain given value.

The threshold of sensitivity of the instrument should be selected in such a manner that the minimum voltage obtained at point A should not be larger than the operating voltage.

In order to obtain at the output of the null-type instrument one pulse only per cycle, it is necessary to preserve certain relations, since an arbitrary raising of the instrument's operating voltage may lead to a deteriorated definition—the lighted point may become blurred.

Fig. 4a shows a case when for a certain time the amplitude of the compensating voltage remains constant and equal to that of the measured voltage. Then beats will occur, whose nodes at points A_1, A_2 . . . . . —correspond to points at which the phases of the two voltages coincide, i.e., to the instants of compensation. However, in fact the amplitude of the compensating voltage varies over one cycle from 0 to its maximum, and the amplitudes become equal only for one instant (see Fig.4b).

Since at the instant of amplitude equality the phases of the voltages may not coincide, the resultant voltage will attain a certain minimum instead of becoming zero.

Let us determine this minimum voltage. At the instant of compensation, angle $\Delta\omega t = (\omega_x - \omega_k)t$ between vectors U_x and U_k is not larger than a few degrees and it is then possible to assume that $\cos \Delta\omega t \approx 1$. The resultant voltage which corresponds to the minimum ordinate of the envelope (point A in Fig.3) is found from the equation:

$$U_r = U_x - U_{k.m} \frac{t}{T_c}. \quad (5)$$

By taking $\cos \Delta\omega t = 1$ we assume that the compensation is attained when the vector phases coincide. By examining Figs.2 and 4 it becomes clear that voltage ΔU, which corresponds to the null-type instrument's threshold of sensitivity, should not exceed half the increment of the compensating voltage between two nodes (in Fig.4 this corresponds to half the distance between two turns of the Archimedian spiral, a distance determined by frequency $\Delta\omega = \omega_x - \omega_k$). From the above it also becomes clear that the resultant voltage at point A will be at its maximum when the end of

the measured vector falls precisely in the middle between two turns of the Archimedian spiral, i.e., when the equality of the measured and compensating voltage amplitudes is attained at the point in which the two vectors are in phase opposition.

Hence,

$$\Delta U = \frac{1}{2}(U_{к_{t+T}} - U_{к_t}), \tag{6}$$

where $T = 2\pi/\Delta\omega$ is the best period.

From the preceding reasoning we know that

$$U_{к_t} = \frac{t}{T_c} U_{к.м}. \tag{6a}$$

We also know that the best period is equal to

$$T = \frac{2\pi}{\omega_x - \omega_к} = \frac{1}{f_x - f_к}, \tag{6b}$$

then

$$\Delta U = \frac{U_{к.м}}{2T_c(f_x - f_к)}. \tag{7}$$

If the voltage tolerance

$$\delta = \frac{\Delta U}{U_{к.м}} \cdot 100\%, \tag{8}$$

is expressed in percentage of its maximum value, the required frequency difference $\Delta f = f_x - f_k$ can easily be calculated from the formula

$$\Delta\varphi = \frac{50}{\delta T_c}. \tag{9}$$

Let us note that for a given voltage tolerance ΔU the maximum phase error $\Delta\varphi$ is determined from the relation

$$\Delta\varphi = 2\arcsin\frac{\Delta U}{2U_x} \tag{10}$$

or if we take into consideration that angle $\Delta\varphi$ is small, we obtain

$$\Delta\varphi \approx \frac{\Delta U}{U_x}, \tag{11}$$

i.e., the phase error is equal to the relative error expressed in radians.

The duration of one cycle T_c is determined from the following considerations: for a constant measured voltage vector the interval between two consecutive flashes will be equal to T_c, and for a changing vector it will differ from T_c. If we assume that the flashes will follow one another at an average time interval of T_c, it is obvious that for the observer to see a continously glowing point the interval T_c must not exceed 0.1 sec for a normal screen and 1-2 sec or more if the screen has a large afterglow.

In the long run the oscillograph screen and hence the time interval T_c must be chosen according to the frequency of the measured signal so as to make Δf one order lower than f_k, otherwise for relatively large values of Δf the envelope will contain a small number of carrier frequency periods and the detection and smoothing of pulsations at the input of the null-indicator relay element will become difficult.

The spiral scanning of the beam on the oscilloscope screen can be produced by two methods:

First method of scanning. The scanning of the electron beam is made at an angular velocity corresponding to the compensating voltage frequency. Fig.1 shows a circuit representing this method of scanning. At the output of the phase-splitting device there will be two voltages with a phase difference between them of 90°. Since the phase-splitting device consists of a linear quadripole, the amplitude of these voltages will also vary linearly and periodically from zero to a maximum. The oscilloscope beam will describe on the screen an Archimedian spiral similar to that traced by the end of the compensating voltage vector U_k. It will thus be possible to determine on the screen not only the amplitude of the measured voltage, but also its phase angle with respect to a coordinate axis which conventionally can be represented by the horizontal axis on the screen.

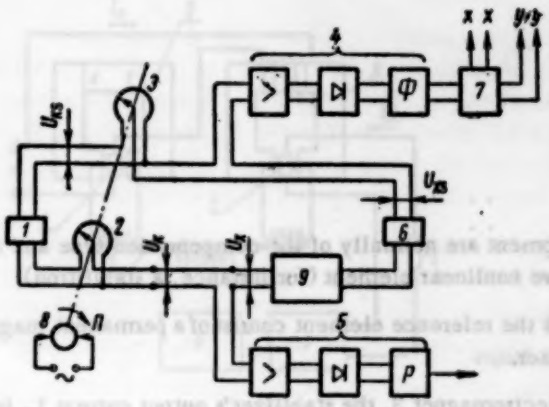

Fig. 5

In order to be able to observe the measured vector it is necessary to make the luminous point fall on exactly the same place after each cycle. This point will then remain stationary until the measured vector changes its value. The luminous points will coincide when the k+1-th flash will follow on the k-th flash at a time interval equal to a whole number of compensating voltage periods. Since the flashes occur at beat notes and hence are spaced by a whole number of voltage periods, it is sufficient to make the beat period a multiple of the compensating voltage period in order to make the luminous points coincide:

$$\frac{T}{T_k}=n, \tag{12}$$

where n is an integer, or

$$\frac{f_k}{f_x-f_k}=n. \tag{13}$$

Second method of scanning. The electron beam is scanned over the Archimedian spiral with an angle of velocity corresponding to the difference of the measured and compensating voltage angular frequencies.

In this case the measured and compensating voltages are not restricted by rigid conditions, which is a decided advantage of this method. However, it is necessary to have an alternating voltage U_{xs} of a constant value whose frequency is equal to that of the measured voltage. The schematic of the instrument with a frequency difference scanning is shown in Fig. 5.

Voltage U_{xs} is obtained from source 6 which supplies the tested circuit 9. The scanning voltage is obtained by detecting the difference between voltage U_{xs} and voltage U_{ks} which is provided by the compensation voltage source and is equal in magnitude to U_{xs}. The detection is accomplished in the envelope selection channel 4 which consists of an amplifier, a detector and a filter.

In the circuit constructed by the authors on the basis of the second method of scanning a clear and stable image of the vector was obtained on the screen. The measured voltage frequency f_s was equal to $12.6 \cdot 10^3$ cps. The compensating voltage U_k had a frequency of $f_k = 12 \cdot 10^3$ cps with an amplitude cycle period equal to $T_c = 0.1$ sec. All the units of the device were based on electronic circuits. The maximum value of the measured voltage amounted to 6 v. The error in measuring the vector modulus did not exceed 2-3%, and that of measuring the phase, 3-4°.

The marking of the origin of the co-ordinates can be obtained on the screen by two methods. In the first case a contact operated device 4 (Fig.1) is provided for it. At the instant when potential divider sliders 2 and 3 are in their initial position, contacts of the device 4 close and send a positive pulse to the grid of the cathode-ray tube. A luminous point appears on the screen which shows the origin of the coordinates. In the second case the grid of the cathode-ray tube is provided with a bias which does not completely extinguish the beam, leaving a very faint, hardly noticeable trace. Owing to the fact that the beam repeatedly returns to the zero point and has at that point a relatively small velocity, the zero point obtains a sufficiently bright illumination.

This device can be applied for testing electrical circuits, for visual checking of various technological parameters in measuring nonelectrical quantities by electrical methods, as secondary receiving instruments in remote measuring systems– especially when phase-sensitive transducers are being used, etc.

LITERATURE CITED

1. F. E. Temnikov, Guidance Scanning System, Author's Certificate Application No. 788mor dated August 20, 1933.
2. F. E. Temnikov, Automatic Recording Instruments [in Russian] (Mashgiz, 1954).

NEW DC STABILIZER CIRCUIT

N. N. Evtikhiev

Translated from Izmeritel'naya Tekhnika, No. 10, pp. 39-40, October, 1961

The dc stabilizers used in measurement and testing equipment are normally of the compensation type and use as a reference element either a stable source of emf or a passive nonlinear element (for instance, a stabilitron).

Below we describe a dc stabilizer circuit (Fig.1) in which the reference element consist of a permanent magnet whose stability provides a constant output current in the stabilizer.

By means of Hall transducer 4, placed in the airgap of electromagnet 3, the stabilizer's output current I_{st} is converted into emf E_2 which is compared with emf E_1, obtained from Hall transducer 1 as a result of the interaction of the field of permanent magnet 2 with a field strength H_{N-S} and the alternating current I_n. Current I_n flows in series through Hall transducer 1 and the coil of electromagnet 3.

The emf of Hall's tranducer 1 is equal to

$$\dot{E}_1 = R_{x_1} H_{N-S} \dot{I}_n, \tag{1}$$

where R_X is a constant of transducer 1; H_{N-S} is the field strength in the air gap of permanent magnet 2; I_n is the supply current.

The emf of the Hall tranducer 4 is determined by equation

$$E_2 = R_{x_2} \dot{H}_{em} I_{st} \tag{2}$$

where R_{x2} is the constant of transducer 4; H_{em} is the field strength in the air gap of electromagnet 3; I_{st} is the output current of the stabilizer.

If the core of the electromagnet is made of a ferro-magnetic material with high permeability and the air gap is equal to 0.5-1 mm, it is possible to consider that the reluctance of the core is determined by that of the air gap. In this case (2) can be written with great accuracy in the form:

$$\dot{E}_2 = R_{x_2} \frac{w_2}{\delta_2} \dot{I}_n I_{st}, \tag{3}$$

where w_2 is the number of turns in the coil of electromagnet 3; δ_2 is the air gap in which transducer 4 is placed.

Emf's E_1 and E_2 are compared by means of differential transformer 7. Transducers 1 and 4 are connected to the input windings of the transformer in such a manner that the magneto-motive forces formed by them are in opposition. The output winding of the transformer is connected to the input of an ac amplifier 6. From the power amplifying stage the signal is fed to a phase-sensitive circuit 5. The rectified and filtered current I_{st} is fed to the current electrodes of transducer 4, which is connected in series with load resistance R_1.

Let us show that the stabilized current I_{st} virtually does not depend either on the supply current I_n or the gain of the direct channel providing certain conditions are maintained.

The voltage at the output winding of the differential transformer is equal to

$$|\dot{U}_3| = |\dot{E}_1 - \dot{E}_2| k_t \ . \tag{4}$$

where k_t is the transformation coefficient of the differential transformer.

The value of current I_{st} can be found from the equation

$$I_{st} = k_a S_{ph} |\dot{U}_s|, \tag{5}$$

where k_a is the gain of the amplifier (it was assumed for simplicity that the amplifier does not change the phase of the input signal vector); S_{ph} is the conversion factor of the phase-sensitive rectifying circuit.

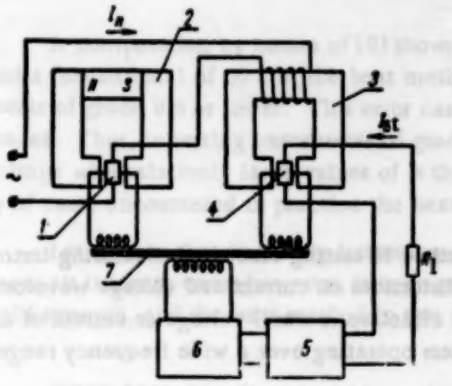

Fig. 1

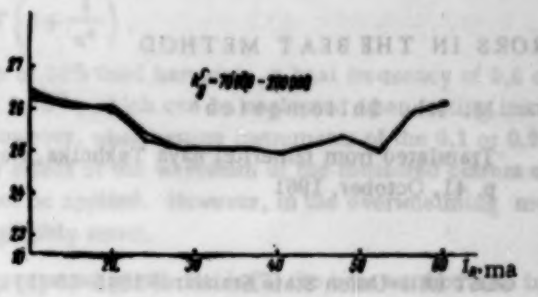

Fig. 2

The conversion factor of a phase-sensitive rectifying circuit is equal to

$$S_{ph} = k \cos \psi, \tag{6}$$

where k is a constant depending on the circuit parameters; ψ is the phase angle between the voltage vector U_s and the reference voltage vector of the phase-sensitive circuit; angle ψ can always be made equal to zero.

By means of (4), (1), and (3) expression (5) can be written as

$$I_{st} = \frac{k_t k_a S_{ph} R_{x_1} H_{N-S} |\dot{I}_n|}{1 + k_t k_a S_{ph} R_{x_1} \frac{w_2}{\delta_2} |\dot{I}_n|}. \tag{7}$$

Providing condition

$$k_t k_a S_{ph} R_{x_1} \frac{w_2}{\delta_2} |\dot{I}_n| \gg 1 \tag{8}$$

is maintained, expression (7) can be simplified to

$$I_{st} = \frac{R_{x_1}}{R_{x_2}} \frac{\delta_2}{w_2} H_{N-S}. \tag{9}$$

It will be seen from (9) that the value of the current in the load is virtually independent of current I_n, the direct channel gain $k_t k_a S_{ph}$ and the load resistance R_1, providing condition (8) is maintained. The stability of current I_{st} depends only on the stability of the permanent magnet and the ratio R_{x1}/R_{x2}. Thus, the schematic shown in Fig.1 can serve as a source of a stable dc current.

The above dc stabilizing method was tested out on an experimental model. The reference element consisted of a magnico alloy permanent magnet with an air gap induction of 640 gauss.

The electromagnet consisted of a permalloy toroidal core with an air gap of 1.1 mm and a winding of 5000 turns. Hall transducers were made of antimonous indium, had the dimensions of 7.3×4.8×0.5 mm and 8×4.5×0.5 mm. Their constants were $0.19 \cdot 10^{-5}$ and $0.2 \cdot 10^{-5}$ v·m/amp^2. The differential transformer had two primary windings of 400 turns each and a secondary winding of 1200 turns. The ac amplifier was transistorized. Its gain could be controlled from 50 000 to 450 000. The amplifier noise referred to its input amounted to less than 1 μv. A ring circuit was used for the phase-sensitive rectifying stage. The phase-sensitive stage was preceded by a power amplifying stage.

Tests of the stabilizer model have shown that variations of the supply current I_n from 25 to 45 ma altered the stabilizer output current I_{st} by less than 0.4% (Fig.2). With variations in I_n amounting to ±15% the value of I_{st} remained constant with an accuracy of 0.1%. A variation in the amplifier gain by a factor of 3 (from 70 000 to 200 000) and of the load resistance from 3 to 40 ohm produced changes in the current I_{st} not exceeding 0.4%.

ERRORS IN THE BEAT METHOD

M. Kh. Shliomovich

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GOST (All-Union State Standard) 1845-59 [1] specifies the beat method in testing electrical measuring instruments for the effect of external magnetic fields [2] and for the effect of distortions on current and voltage waveforms. In the second instance it was assumed that if an instrument measuring the effective (actual) voltage or current of any waveform (electrostatic voltmeters or thermal and thermoelectric ammeters operating over a wide frequency range) is fed with a variable represented by equation

$$a = A_{1m}[\sin \omega t + \alpha \sin (n\omega t + \Delta\omega t)], \tag{1}$$

the readings of this instrument will correspond at any instant to the effective value

$$A = \frac{A_{1m}}{\sqrt{2}} \sqrt{1+\alpha^2}, \tag{2}$$

where A_{1m} is the amplitude of the voltage or current first harmonic; α is the ratio of the n-th harmonic amplitude to that of the first harmonic; ω is the angular frequency of the first harmonic; $\Delta\omega$ is the beat frequency.

However, tests of electrostatic voltmeters by the beat method have not confirmed the above assumptions, namely in measuring a voltage represented by (1) readings of electrostatic voltmeters periodically varied at the beat frequency $\Delta\omega$.

Let us show that this phenomenon has a sound theoretical explanation and is the result of an inherent error in applying the beat method for determining the effect of the waveform on the tested instruments.

It is known [1,2] that for these tests a low beat frequency is used, and since during time $T_B = 2\pi/\Delta\omega$ the effective value of the measured current or voltage varies from period to period for period T of the fundamental frequency, the moving part of the instrument is able to follow these variations owing to the low beat frequency $\Delta\omega$, i.e., the instrument readings vary periodically.

Let us now find for time interval $kT-(k+1)T$, where $k \geq 0$ and $(k+1) \leq T_B/T$, the effective value of the voltage or current represented by (1) for period T:

$$A(k) = \sqrt{\frac{1}{T}\int_{kT}^{(k+1)T} \{A_{1m}[\sin \omega t + \alpha \sin (n\omega t + \Delta\omega t)]\}^2 dt} = \tag{3}$$

$$= A_{1m}\sqrt{\frac{1+\alpha^2}{2} - \frac{[\sin 2\Delta\omega (k+1)T - \sin 2\Delta\omega kT]\alpha^2}{4(n\omega+\Delta\omega)T(1+\alpha^2)}}.$$

Thus the effective value of A(k) is not constant over time interval T_B, and differs from the effective value of A(2), which the instrument should indicate in the presence of a harmonic with a relative amplitude α, by the amount of

$$A(k) - A = -\frac{A_{1m}}{\sqrt{2}}\sqrt{1+\alpha^2} \times \frac{[\sin 2\Delta\omega (k+1)T - \sin 2\Delta\omega kT]\alpha^2}{4(n\omega+\Delta\omega)T(1+\alpha^2)}. \tag{4}$$

This determines the relative error of the beat method

$$\delta_B = \frac{A(k)-A}{A} = \frac{\sin 2\Delta\omega kT - \sin 2\Delta\omega (k+1)T}{4(n\omega+\Delta\omega)T\left(1+\frac{1}{\alpha^2}\right)}, \quad (5)$$

which has a maximum for $k=0$ (or, which is the same thing, for $(k+1)T=T_B$), i.e.

$$|\delta_B \max| = \frac{\sin 2\Delta\omega T}{4(n\omega+\Delta\omega)T\left(1+\frac{1}{\alpha^2}\right)}. \quad (6)$$

A computation by means of (6) shows that in the presence of 30% third harmonic, a beat frequency of 0.5 cps and a fundamental of 50 cps, the beat method error amounts ot 0.15%, which can be neglected when testing instruments of grade 0.5 or lower. This error cannot be neglected, however, when testing instruments of the 0.1 or 0.2 grades. Thus, in testing instruments of grades 0.1 or 0.2 for the effect of the waveform of the measured current or voltage with relatively large values of α the beat method cannot be applied. However, in the overwhelming majority of cases encountered in practice the beat method error is negligibly small.

Let us note that in testing instruments for the effect of external magnetic fields [2] the beat method also introduces an inherent error; however, it is an error within an error, since it only introduces fluctuations in the effective field strength, and the beat method in this instance can therefore always be used.

LITERATURE CITED

1. GOST 1845-59. Electrical Measuring Instruments. General technical requirements.
2. M. Kh. Shliomovich, Izmeritel'naya teknika, 1960, No. 6.

DETERMINING THE PHASE ERROR AND MUTUAL INDUCTANCE OF AIR-CORED TRANSFORMERS AT HIGH FREQUENCIES

N. V. Levitskaya

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The VNIIK (All-Union Scientific Research Institute of the Committee of Standards, Measures, and Measuring Instruments) has developed a method for measuring phase errors and mutual inductance of air-cored transformers at high frequencies.

The phase errors and mutual inductance of air transformers are measured in this method by means of a box of reference capacitances with a known small loss angle, a reference resistance box and a reference current transformer [1].

The schematic measuring circuit is shown in Fig.1.

At balance the following relation holds between the parameters of circuit elements:

$$j\omega M\dot{I}_1 E^{-j\varphi} - j\frac{\dot{I}_1}{\omega C}E^{j\alpha} - \frac{\dot{I}_1}{k}r(1+\lambda)=0, \quad (a)$$

where M is the measured mutual inductance of the air-cored transformer; $\dot{I}_1$ is the current in the primary winding of the air-cored transformer; ω is the angular frequency of the current; C is the capacitance of the reference box; r is the value of the reference resistance; φ is the phase error of the air-cored transformer; α is the loss angle of the reference capacitance box; k is the ratio of the reference current transformer; $\lambda = f + j\delta$ is the complex error of the refer-

ence current transformer; f and δ are the current error and the phase error respectively of the reference transformer.

By separating the real and imaginary parts we obtain the following two conditions for the bridge balance:

$$\omega M - \frac{1}{\omega C} - \frac{r\delta}{k} = 0, \tag{1}$$

$$\varphi + \frac{\alpha}{\omega^2 CM} - \frac{r}{k\omega M}(1+f) = 0. \tag{2}$$

In measuring the mutual inductance and phase error of mutual inductance standards (mutual inductance coils and boxes) at frequencies up to 10 000 cps it is possible to neglect the last term in equation (1) since it is of a second order of magnitude as compared with the remaining terms. If a transformer of the required high grade is chosen it is also possible to neglect variable f as compared with unity. Thus, we shall obtain for the above case the following approximate conditions of bridge balance x:

$$M \approx \frac{1}{\omega^2 C}, \tag{1a}$$

$$\varphi + \alpha \approx \frac{r}{k\omega M}. \tag{2a}$$

Hence, when the bridge is balanced it is possible to determine the phase error of the tested coil from resistance r and its mutual inductance from capacitance C, providing the transformer ratio k and frequency ω are known.

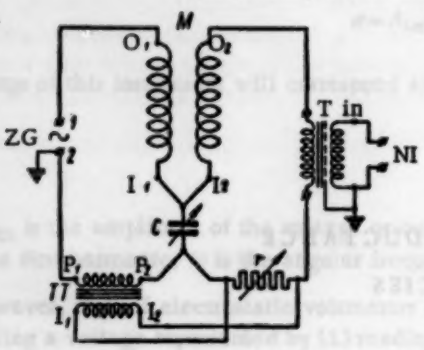

Fig. 1

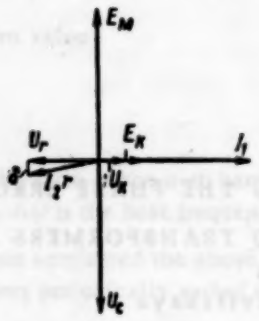

Fig. 2

The above arrangement represents a modified Campbell bridge circuit [2] to which a current transformer TT and resistance r in the secondary circuit are added (see Fig.1) in order to measure the phase error of mutual inductance M (of an air-cored transformer) or the loss angle of capacitor C. By means of this circuit a voltage reversed in phase with respect to the primary current is fed to the null-indicator in order to compensate the air-cored transformer's secondary emf $\dot{E}_k$ which is due to the transformer's phase error, and to compensate voltage U_k due to losses in capacitor C. The operation of the circuit is explained by the vector diagram (Fig.2). At balance the mutual inductance emf = $j\omega M\dot{I}_1$ is compensated by the voltage drop across the reference capacitor $\dot{U}_C = \dot{I}_1/j\omega_C$ which is opposite in phase to the emf.

The sum of voltages $\dot{E}_k + \dot{U}_k$ is compensated by voltage U_r. Voltage $U_r \approx I_2 r$ and is in phase with current I_2 with an error equal to the phase error δ of the reference current transformer.

The peculiarity of the above method as compared with other methods for measuring the phase error and mutual inductance of air-cored transformers without using mutual inductance standards [3, 4] consists in the possibility it provides for measuring these quantities over a sufficiently wide frequency range with the inner or outer ends of their windings connected together (three-pole circuit), i.e., for a completely determined distribution of potentials inside the coil which corresponds to their most common usage.

Moreover, the mutual inductance is measured directly and not by computation from inductance measurements of its windings connected in series aiding and opposing. Thus, the accuracy of the mutual inductance measurements

does not depend on the ratio of the winding inductances to their mutual inductance in the air-cored transformers or mutual inductance standards under test.

The errors in measuring the mutual inductance phase error are determined by the following factors: error in the ratio of the reference current transformer; the reference resistance box error; error in estimating the loss angle of the reference capacitances; and the errors due to the resistance and capacitance of the connecting leads.

The factors which impede phase error measurements and lead to errors include: supply voltage waveform distortions; effect of external magnetic fields and frequency instability during measurements.

In mutual inductance measurements the basic sources of errors include: error in setting the frequency; error in estimating the value of the reference capacitance and the input capacitance at the terminals for connecting the mutual inductance coil. The effect of the input capacitance will increase with the rising input impedance of the coil and the rising measurement frequency.

The main disturbing factor in measuring mutual inductance consists of external magnetic fields, whose effect is especially noticeable for small values of inductance at low frequencies.

The VNIIK has produced an equipment (UMF) according to the above circuit for measuring phase errors and mutual inductance of mutual inductance coils and boxes at frequencies from 400 to 10 000 cps. The equipment provides the measurement of phase errors exceeding one minute and mutual inductances of coils and boxes of a nominal value of 0.1 mh to 0.1 h.

The operating frequency ranges for the nominal reference mutual inductance values are shown in the table attached.

M_{nom}, h	0.1	0.01	0.001	0.0001
Operating frequency, cps	400	400–2500	1000–5000	5000–10000

The operating frequency ranges for the intermediate mutual inductance values are determined by the respective capacitance ranges of the reference boxes.

The measurement errors of this equipment do not exceed the following values: ±10% in measuring phase errors exceeding $1 \cdot 10^{-3}$, and $\pm 2 \cdot 10^{-4}$ in measuring small phase errors; they amount to ± 0.1% in measuring mutual inductances in the range of 0.001 to 0.01 h, and ± 0.2% in the range of 0.0001 to 0.001 h.

The set of reference capacitors consists of two capacitance boxes connected in parallel: a box of large capacitors type ME-59 with a range from 1 to 40 μf developed by the VNIIK specially for the above equipment, and a three-decade capacitance box type MERP of the "Etalon" plant with a range up to 1 μf which incorporates an air capacitor for a continuous capacitance setting. The ME-59 box consists of metal-film (polystyrene) capacitors type MPG. The box capacitances are adjusted not to differ from their nominal value by more than ± 0.1% at 1000 cps. In designing the box account has been taken of the effect of the inductance and resistance of connecting leads on the capacitance and loss angle of the capacitors.

The loss angle tangent of the capacitance box does not exceed $5 \cdot 10^{-4}$ at 1000 cps and $2 \cdot 10^{-3}$ at 5000 cps. The capacitance variation of the box in the operating frequency does not exceed 0.2% and is known with the required accuracy.

The MERP box has mica capacitors of grade 0.1.

The above boxes provide measurements of mutual inductance and phase errors of mutual inductance standards in the above-mentioned ranges of their values and frequencies.

The majority of mutual inductance standards have a phase error of the order of 10^{-4} to 10^{-3} rad at 1000 cps and proportionately larger at higher frequencies. In order to determine the phase error with an accuracy of 5-10% it is necessary to balance out the mutual inductance emf up to the fourth or fifth decimal place. This is attained by a sufficiently fine control and high stability of the reference capacitors, a correspondingly high stability of the measurement frequency, a sensitive measuring circuit and a selective null indicator. The same factors provide the required accuracy in measuring capacitance.

In the experimental model the measuring circuit is supplied from an external audiofrequency oscillator ZG-12. The frequency of the oscillator voltage is set and maintained during measurements by means of a cathode-ray oscilloscope EO-4 against the standard 1000 cps frequency transmitted by the time service and the frequency of the VNIIFTRI (All-Union Scientific Research Institute of Physicotechnical and Radio-technical Measurements) with an error smaller than 0.001%.

In sets intended for commercial operation supplies are obtained from a crystal quartz oscillator type KGA through a power amplifier. Balance is shown by means of a cathode-ray null indicator type "Élur-2" of the Leningrad "Étalon" plant.

The phase error compensation circuit includes a multi-range current transformer I-55 whose transformation ratio error does not exceed 2% at 400 to 1000 cps.

The phase error of the measured mutual inductance standard is read off a nonreactive resistance box type R555.

In designing the set, measures have been taken to reduce the capacity of the input terminals and the mutual inductance of the primary current circuit and the secondary emf circuit of the tested coil, as well as the effect of external magnetic fields. The latter is achieved by reducing the areas of the above circuits as far as possible. A sufficiently small input capacitance of the set with a small area of the secondary emf circuit is attained by fixing the go and return conductors of the circuit side by side at a distance of the order of 10 mm. The mutual inductance of the circuits is reduced by separating them from each other and by a rational selection of junction points (see Fig.1).

A rational selection of junction points also reduces the effect of the resistance of connecting conductors on the phase error measurements.

LITERATURE CITED

1. N. V. Levitskaya, "Method of determining phase errors in mutual inductance coils." Foremost Scientific, Technical and Production Experience, subject No. 27, No. 3-59-80/34, [in Russian] (VINITI, Moscow, 1959).
2. B. Hague, Alternating current bridge methods, London, 1945, p. 470.
3. M. I. Levin and R. M. Demidova, "Measurement of phase errors in mutual inductance coils." Scientific Reports of Higher Educational Institutions. Series on "Electrical technology and automation," No. 3 [in Russian] (Sovetskaya nauka press, Moscow, 1958).
4. A. Z. Veksler, Izmeritel'naya tekhnika, 1959, No. 6.

UNIVERSAL AVO METERS

N. I. Tyurin, A. M. Lyubarskaya, and V. P. Boguslavskii

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The problems raised in our article printed in 1960, No. 12 issue of this journal have provoked comments, mostly from instrument-makers.

The greatest attention has been paid to the problem of classifying and selecting a rational series of instruments. M. A. Ogorelin and V. S. Skryabinskii ("Tochélektropribor" plant) note that "the classification of universal instruments adopted by the plant and noted in the article is, of course, incomplete and deals essentially with one group of such instruments only, namely, with those intended for use under normal atmospheric conditions in plants, in research institutions, etc." In their opinion two other groups of instruments which are essentially different from the above can be cited: "One such group should include instruments intended for the public, radio-amateurs, etc. The distinctive characteristics of this group of instruments should consist of simplicity, a robust design suitable for mass production, and as a consequence of this, preference over accuracy and universality but not the sensitivity of instruments."

The suggestions of V. I. Nymm are similar to the already mentioned, however, he considers that the reduction of sensitivity in the instruments for amateurs is also possible. M. A. Ogorelin and V. S. Skryabinskii suggest as a possible version of such instruments a set comprising one relatively simple and sensitive basic instrument (for instance, a dc voltmeter) and a large number of attachments to suit any requirements. The attachments should be made to couple easily, conveniently and quickly to the main instrument.

The second group of instruments according to them should consist of those intended for field testing. The basic characteristics determining the suitability of such instruments should consist of a robust and reliable design and a wide range of operating temperatures, whereas a low price of the instrument is no longer essential. The cases of such instruments should form a part of them and should protect them from dust, humidity, shocks, etc. The same case should contain all the instrument's attachments, such as probes, connecting leads, etc.

M. A. Ogorelin and V. S. Skryabinskii do not exclude the possibility of establishing other groups of instruments with special characteristics. For instance, it is quite feasible that highly sensitive instruments incorporating electron tube or transitorized amplifiers will be made highly universal with a large number of scales and covering a wide range of measurements. O. S. Andreev and M. I. Chernin of Omsk write essentially the same when they stress the advantages of the AVO-5M1 instrument, which is highly sensitive and has wide measuring ranges, but at the same time possesses several shortcomings.

The workers of the "Elektroizmeritel'" plant (Zhitomir) M. M. Baboglo, A. G. Nazarchuk, and N. I. Nevmerzhitskii suggest including in the classification a wider range of combined instruments. They write: "These instruments should provide measurements of the active and reactive components of current and voltage, and phase angles; thus, they can no longer be considered as AVO meters."

The authors of the original article had in view, however, precisely AVO meters, i.e., one definite but sufficiently general group of all the existing combined instruments. Abroad, this group is known under the name of "testers." The classification and establishment of a rational series of instruments even in this group meets with considerable difficulties (which can be gauged from the contradictory comments). Hence, the posing of the problem for classifying combined instruments in general should not delete from the agenda the classification of AVO meters as a definite group of instruments.

M. S. Veksler (VNIIÉP, All-Union Scientific Research Institute of Electrical Measuring Instruments) suggests extending the proposed classification by including in it moving-iron instruments which measure the effective value of voltage and current as distinct from the detector-type instruments whose reading is proportional to the mean current.

Moving-iron instruments possess considerable advantages, since they do not require switching from ac to dc measurements, and they use the same scale for both cases.

At present it is possible to make universal moving-coil instruments of grade 1.5 with 12-15 scales which cover a current range from 7.5 ma to 30 amp, and a voltage range from 3 to 600 v, with a frequency range up to 500 cps.

This suggestion is undoubtedly interesting. However, firstly these instruments are still being developed, and secondly if it does not become impossible to measure resistance with them they cannot be included in the group considered in our article.

O. S. Andreev and M. M. Chernin consider that further development of universal instruments should aim both at designing high-precision costly instruments, and simpler and cheaper instruments for radio-amateurs, students, etc.

The above comments on our article have contributed essential additions to the proposed classification of universal AVO meters. On the basis of these suggestions it is possible to outline the following classification of AVO meters.

The classification is based on the sensitivity of the mechanism for dc measurements which corresponds either to the current required for a full-scale deflection or to the ohm/volt ratio.

It is possible to suggest the following 4 groups: I. 0.5-1 μa or 1000-2000 ohm/v; II. 50-100 μa or 10 000-20 000 ohm/v; III. 5-10 μa or 100 000-200 000 ohm/v; IV. Not higher than 1 μa or 1 000 000 or more ohm/v.

At the present stage of instrument-making the instruments of the last group must in general include amplifiers.

Within each group instruments should be assigned according to their use in the following manner: 1) for laboratory work (grade 0.5-1.5); 2) for work and repair shops, mechanics, etc. (grade 1.5-2.5); and 3) for amateurs (grade 2.5-4).

With respect to size and finish each group should contain the following classes: A) portable (normal size); B) traveller (small size); C) pocket (minature).

Finally, it is advisable to classify AVO meters according to the frequency of the voltage and current they measure into four groups: a) low commercial frequencies (45-55 cps); b) low audio-frequencies (up to 500 cps); c) medium audio-frequencies (up to 1000-1500 cps); and d) high audio-frequencies (up to 10-20 cps).

Classifications according to the conditions of their use and other characteristics given in GOST (All-Union State Standard) 1845-59, obviously remain in force.

At first sight it would appear that the above arrangement would provide more types than exist at present. It is true that, even if we omit GOST 1845-59, the number of types provided by the combination of the above-mentioned four group characteristics amounts to 144. Let us keep in mind, however, that this is only an outline, and in working out a practical classification many combinations will be impossible or at least irrational.

For instance, a group IV instrument cannot in practice be made portable for commercial or audio-frequencies. Even after the selection of types which are feasible in practice and desirable, their number will still be large. However, this diversity will differ essentially from the chaotic diversity of the instruments which are being produced at present. Many existing instruments belong to the same group, but differ from one another only in the selection of ranges, the shape of their cases and the method of switching, i.e., only by secondary characteristics which may or may not be important. Unfortunately these characteristics have not been mentioned in any of the comments on our article received by us.

Only V. I. Nymm deals with the rational selection of measuring ranges. He considers it advisable for multi-range instruments to select ranges with full-scale readings in the ratio of 1, 3, 10, 30, ... where each preceding range covers $^1/_3$ of the subsequent range.

The series of measuring ranges suggested by V. I. Nymm is theoretically correct, but it cannot be generally accepted, since it does not take into consideration certain practical requirements, and in particular nominal values of currents and voltages. For instance, according to his suggestion we shall have full-scale readings of 100 and 300 v, and will be obliged to measure voltages of 110 and 127 v at the beginning of the second third of the scale.

V. I. Nymm himself rejects the ranges suggested by him in dealing with ranges for radio-amateurs' instruments, for which he suggests the following scales: U = 6–15–150–600 v, U ~ 15–150–600 v, I = 0.15–15–150–1500 ma.

On the problem of protecting instruments from overloading there is a difference of opinion. O. S. Andreev and M. M. Chernin support the necessity for such protection, but M. A. Ogorelin and V. S. Skryabinskii object to it on grounds which deserve consideration. They consider that universal instruments owing to their small internal consumption can withstand considerably larger overloads than ordinary instruments. Therefore, it is possible in this case to make more stringent the requirements for sustaining short overloads; moreover, it is necessary to differentiate these requirements with respect to ranges (so as not to test, for instance, an instrument on the 600 v range by 6000 v overloads which the instrument cannot withstand and whose probability of occuring in use is practically zero).

On the other hand, everyone agrees with the need for specifying more precisely safety precautions required in low-power measurements, since the existing regulations impede the production of very necessary equipment. The final word rests with the organizations in charge of safety precautions.

We hope that the results of the discussion carried out in this journal will be taken into consideration by the VNIIÉP and the "Tochélektropribor" plants which are developing standards for universal combined electrical measuring instruments.

MEASURING THE PERMITTIVITY OF SEPARATE GRAINS

A. M. Basov and V. N. Shmigel'

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For separating grains of cereals by electrical means we have developed a technique of determining permittivity of individual ellipsoidal particles [1].

It is known that a spheroid placed in a uniform electric field is affected by the moment of rotation M_e [2]. Let us convert its formula into a form convenient for us:

$$M_e = \frac{\varepsilon_0 E_0^2}{2} V_e \Phi_3 \sin 2\gamma \qquad (1)$$

For a given volume of the spheroid V_e and coefficient Φ_3, and a constant external field strength E_0 the value of M_e depends on the tilt angle of the major axis of the spheroid to the plane of the electrodes which produce the field. Moreover, M_e will be at its maximum when $\gamma = 45°$.

If a spheroid of known dimensions and permittivity (which we shall henceforth consider as a standard) is suspended by its center of gravity from an unstretchable thread in a uniform electric field, the spheroid will begin to rotate under the effect of M_e and will overcome the turning moment of the thread which is:

$$M_t = A\varphi l, \qquad (2)$$

where A is a coefficient which accounts for the elasticity of the thread; φ is the angle of rotation; l is the length of the thread.

Considering the rotation angle of the thread to be the same as the tilt angle of the spheroid's major axis to the plane of the electrodes we can write:

$$M_t = A\gamma l. \qquad (3)$$

Expressions (3) and (1) show respectively that M_t varies linearly, and M_e proportionately to the sine of twice the angle γ. The relation between M_e and M_t to γ is shown in Fig.1. By varying the field strength we obtain a family of curves $M_e = f(\gamma)$; moreover, the ordinates of M_e rise with an increasing field. Since the torque of the field is counteracted by that of the thread, a stable balance is obtained at a certain value of γ. In Fig.1 the points of intersection between $M_e = f(\gamma)$ and $M_t = F(\gamma)$ determine the various values of the field strength at points of balance (stability) of the spheroid particle for various tilts of its major axis.

Let us now suspend by the same thread a spheroid of known dimensions but unknown permittivity. By changing the field strength let us rotate the unknown spheroid by means of the turning moment M_{eu} through the same angle as the standard spheroid. We shall then obtain the following conditions for equal torques in the standard (M_e) and tested (M_{eu}) spheroids:

$$M_e = M_t \; ; \quad M_{eu} = M_t \, , \qquad (4)$$

and hence,

$$M_e = M_{eu}. \qquad (5)$$

If we insert in (5) the values of the standard and tested spheroids obtained from (1) and perform several simple transformations by expressing the volumes of the standard and tested spheroids as $V_e = \pi a^3 K^2/6$ and $V_{eu} = \pi a_u^3 K_u^2/6$ we shall obtain an expression for coefficient Φ_{3u}. This coefficient which characterizes the shape and relative permittivity ε_{ru} of the tested particle as a spheroid is equal to:

$$\Phi_{2u}=\frac{u^2}{u_u^2}\Phi_2\frac{a^3K^2}{a_u^3K_u^2}, \tag{6}$$

where u/u_u is the ratio of the voltages applied to the electrodes (according to the instrument reading) in order to rotate the standard and tested spheroids through the same angle; a, a_u, K, and K_u are the major axes and the coefficients of sphericity of the standard and tested spheroids respectively.

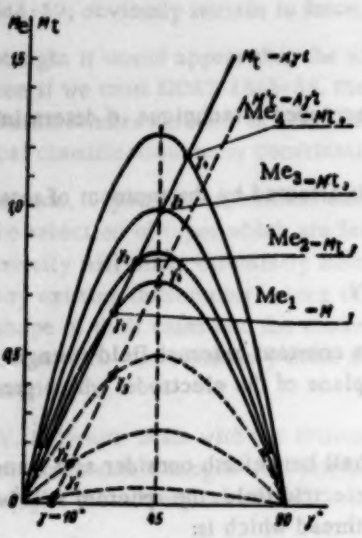

Fig. 1

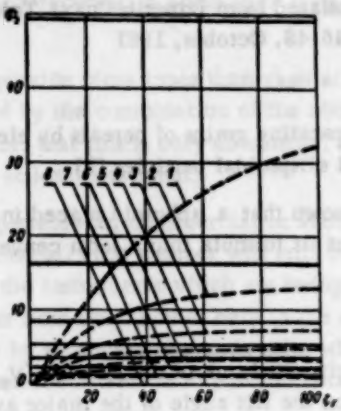

Fig. 2. Dotted lines represent the relation of ϕ_2 to ϵ_r for K equal to: 1 = 0.1, 2 = 0.2, 3 = 0.3, 4 = 0.4, 5 = 0.5, 6 = 0.6, 7 = 0.7, and 8 = 1; full lines represent the limits of ϕ_2 for $\epsilon_r = \infty$ corresponding to the respective values of K.

The coefficient of sphericity K is equal to the ratio of the minor to the major axis of revolution of the spheroid. If it is an ellipsoid it must be reduced to a spheroid by taking for the miner axis the geometric mean of two minor axes.

On the basis of [2,3] we have derived an analytical relationship of ϕ_2 to ϵ_r for various values of K, which is illustrated graphically in Fig.2.

$$\Phi_2=\frac{\Phi_1'-\Phi_1}{\left(\frac{1}{\varepsilon_r-1}+\Phi_1\right)\left(\frac{1}{\varepsilon_r-1}+\Phi_1'\right)}, \tag{7}$$

where ϕ_1 and ϕ'_1 are the axial attenuation factors of the field along the major and minor axes respectively of the spheroid. These coefficients vary in the range of $0 \le \phi_1 \le 0.333 \le \phi'_1 \le 0.5$ and are equal to

$$\Phi_1=\frac{K^2}{2\sqrt{(1-K^2)^3}}\times\left[\ln\frac{1+\sqrt{1-K^2}}{1-\sqrt{1-K^2}}-2\sqrt{1-K^2}\right];\qquad \Phi_1'=\frac{K^2}{4\sqrt{(1-K^2)^3}}\times\left[\frac{2\sqrt{1-K^2}}{K^2}-\ln\frac{1+\sqrt{1-K^2}}{1-\sqrt{1-K^2}}\right]. \tag{8}$$

For a practical application of these relationships we have plotted a graph $\phi_{2u}=f(\epsilon_{ru})$ for the values of K between 0 and 1 in intervals of 0.01 (or 0.005). From this graph the required value of ϵ_{ru} is determined by using the experimental data and calculating ϕ_{2u} from (6). The value of ϕ_2 for the standard spheroid is calculated from (7).

The above propositions are also applicable for determining the permittivity of disc-shaped particles, but curves $\phi_2=F(\epsilon_r)$ for such particles have different values.

For the experimental part of this investigation we have designed and constructed a special equipment whose general view is shown in Fig.3.

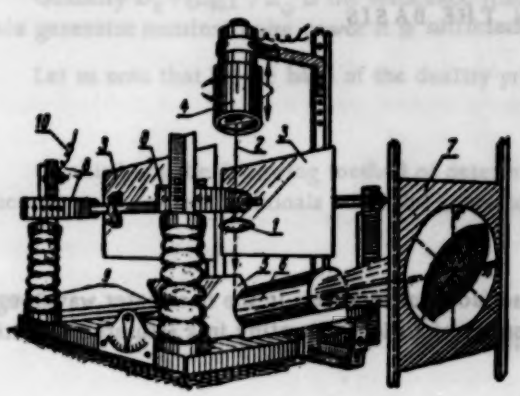

Fig. 3

Spheroid 1 suspended by thread 2 is placed in an electric field formed by flat electrodes 3. The thread is attached by a stressed wire suspension to the center of the objective of a point illuminator 4. The shadow of the spheroid falls on mirror 5 and is reflected from it through objective 6 onto screen 7 which is calibrated in degrees. The distance between the electrodes is adjusted by displacing plates 8 of the equipment. One of the electrodes is grounded, and the other which is mounted on insulators 9 is supplied with a voltage from a rectifying device through conductor 10. A mirror-galvanometer illuminator was used in this equipment.

We measured the permittivity of three types of wheat: "Gordieforme-10" (hard), "Al'bidum-3700," and "Iskra," as well as of "Vyatka" rye and "Pobeda" oats. The tested grains were selected to have a shape approaching as closely as possible a spheroid. The standard spheroid was made of solder.

According to (1) for $\gamma = 0$ the particle will not be affected by the rotation moment of the field. In practice it is very difficult to place the body so that $\gamma = 0$, therefore, it was placed at an angle of $\gamma = 10°$. Next the body was rotated (by raising the field strength) to a position of $\gamma = 45°$. This position is marked in Fig.1 by points γ'_1, γ'_2, γ'_3, and γ'_4. The line of rotation moment M'_t is displaced parallel to M_t when the initial value of $\gamma = 0$.

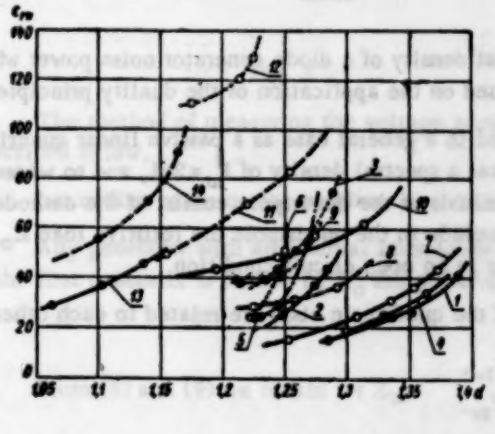

Fig. 4. 1, 2, and 3, for "Iskra" wheat with W values of 8, 20, and 32% respectively; 4, 5, and 6 for "Albidum-3700" wheat; 7, 8, and 9 for "Gordieforme-10" wheat; 10, 11, and 12 for "Vyatka" rye; 13 and 14 for "Pobeda" oats (at $W = 32\%$ $\epsilon_{ru} = \infty$).

Having experimented with the orientation of each separate grain in the field by the well-known methods [4] we determined its specific gravity d and moisture content W.

In order to plot the relation of permittivity of the grain to its specific gravity it is necessary to have data at a constant moisture content. Therefore the moisture content of grain was reduced to three values, namely, of 8, 20, and 32%.

The relation $\epsilon_{ru} = f(d)$ is shown graphically in Fig.4. A certain dispersion of the points is due to the following: 1) for calculation purposes it was assumed that the grain has the shape of an ideal spheroid, whereas its actual shape approaches an ellipsoid; 2) the grains have different chemical compositions and structures. For instance, in the same brand of wheat there can be farinaceous and hyaline grains which have different structures. Similar conditions obtain in determining the permittivity of minerals.

The above method of determining the permittivity by means of moments of rotation can be used for any dielectric spheroid (or disc-shaped) particles in order to determine their separational properties. This method can also be used in the case when the measurement of permittivity by other methods leads to the destruction of the structural coupling in the particles or to the appearance of an additional component, a filler, which distorts the actual value of permittivity.

LITERATURE CITED

1. V. N. Shmigel', Author's Certificate No. 137582, Bulletin of Inventions, 1961, No. 8.
2. D. A. Stretton, Electromagnetic Theory [in Russian] (GITTL, 1948).
3. A. L. Mikaelyan, Radiotekhnika, 1955, Vol. 10, No. 1.
4. N. I. Sosedov and V. A. Shvetsova, Determining the Moisture Content of Separate Grains [in Russian] (Works of the VNIIZ, 1953, No. 25).

CALIBRATION OF DIODE NOISE GENERATORS ON THE BASIS OF THE DUALITY PRINCIPLE

M. M. Karliner and Yu. K. Sorokin

Translated from Izmeritel'naya Teknika, No. 10,
pp. 49-52, October, 1961

Diode noise generators are often used for measuring the noise factor of receivers in the decimeter wavelength range. It is known that the square of the noise current spectral density of a diode operating in a saturated condition is equal to [1].

$$I_{\omega}^2 = 2eI_{=}, \tag{1}$$

where e is the charge of an electron; $I_{=}$ is the diode current.

On the basis of this relationship and a simple equivalent circuit of a diode noise generator, whose parameters at low frequencies are usually known, it is possible to find the nominal power of the diode generator noise [2].

It is no longer possible to consider the parameters of the equivalent circuit to be known in the decimeter waveband, especially at its short-wave end, owing to the presence of stray reactances. Moreover, even the form of the equivalent circuit in the decimeter band is normally unknown. Hence, in order to determine the noise power of a diode generator it has to be calibrated against a heat standard. The equipment required for this purpose is very complicated and seldom available.

In this article we suggest a method for determining the spectral density of a diode generator noise power which does not require complicated special equipment. The method is based on the application of the duality principle.

Basic relationships. A diode noise generator can be represented in a general case as a passive linear quadripole to whose input an ideal noise current generator is connected which has a spectral density of $I_{\omega}^2 = 2eI_{=}$ and to whose output is connected a nominal resistive load Z_0 (Fig.1). The input terminals of the quadripole consist of the cathode and anode of the noise diode. In subsequent calculations we shall also include in the quadripole the resistive load Z_0, so as to make the resultant quadripole with terminals ab and cd operate in an open circuit condition.

The spectral density of the current and voltage at the input of the quadripole abcd are related to each other by the following expressions

$$\begin{aligned} U_{1\omega} &= Z_{11} I_{1\omega} + Z_{12} I_{2\omega}, \\ U_{2\omega} &= Z_{21} I_{1\omega} + Z_{22} I_{2\omega}. \end{aligned} \tag{2}$$

In our case $I_{2\omega} = 0$ and therefore

$$\begin{aligned} U_{1\omega} &= Z_{11} I_{1\omega}, \\ U_{2\omega} &= Z_{21} I_{1\omega}. \end{aligned} \tag{3}$$

The power dissipated in the resistive load Z_0 will be equal to (in the band of 1 cps)

$$P_1 = \frac{|U_{2\omega}|^2}{Z_0}. \tag{4}$$

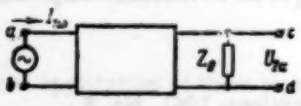

Fig. 1

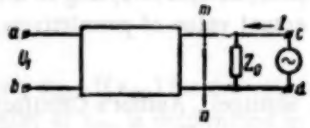

Fig. 2

By inserting the value of $U_{2\omega}$ from (3) we obtain

$$P_1 = \frac{|Z_{21}|^2}{Z_0} |I_{1-}|^2. \quad (5)$$

Quantity $Z_X = [Z_{21}]^2 / Z_0$ is the resistance load transferred to the noise current circuit. In order to determine the diode generator nominal noise power it is sufficient to find the value of Z_X.

Let us note that on the basis of the duality principle

$$Z_{21} = Z_{12}. \quad (6)$$

On this basis the following method of determining Z_X is suggested (Fig.2). Let us connect a sinewave current I generator to the output terminals cd of the quadripole. Then according to (2) the voltage at terminals ab will be

$$U_1 = Z_{12} I, \quad (7)$$

whence

$$|Z_{12}|^2 = |Z_{21}|^2 = \frac{|U_1|^2}{|I|^2}. \quad (8)$$

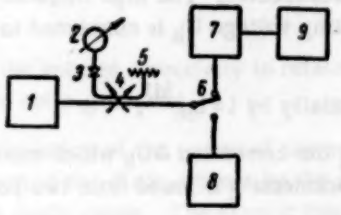

Fig. 3

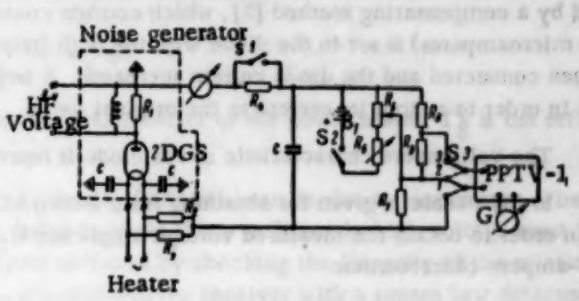

Fig. 4

The method of measuring the voltage across terminals ab, i.e., between the anode and cathode of the diode, is described below.

Let us first examine the problem of determining current I.

Any generator with an internal impedance Z_0 is equivalent to a current generator shunted by impedance Z_0. If the first generator is loaded by Z_0 the power in the load will be

$$P = \frac{|I|^2 Z_0}{4}. \quad (9)$$

From (8) and (9) we obtain for Z_X

$$Z_X = \frac{|U_1|^2}{4P}. \quad (10)$$

It follows from the above that a technique of measuring Z_X must consist of the following: Instead of the generator of current I and load Z_0 the diode noise generator is connected to a generator with a matched output. The power of generator P is first measured by means of a matched power meter. Next the voltage U_1 between the anode and cathode of the diode is measured and then Z_0 is calculated from (10). For calibration purposes such measurements are made at several points of the required frequency range.

A certain inconvenience of the above method consists in the requirement of a powerful generator with a matched output.

It is, however, possible to change the testing technique and use an unmatched generator. In order to explain this let us examine Fig. 2. Let us assume that a matched generator with a nominal power P has been connected to terminals mn and that voltage U_1 has been measured across terminals ab. Since the output of the generator is matched the power of the incident wave in cross section mn will be P. Let us now replace the matched generator with an unmatched one, which provides an incident wave of the same power P. It is obvious that the output voltage U_1 will not change. Hence, the previously described technique of measurements can be changed in the following manner. The

available generator (which is not supposed to be matched) is first connected through a directional coupler to a matched power meter whose readings indicate the power of the incident wave. The generator is then connected to the noise generator under test and if the power of the incident wave has changed it is reestablished to its previous value. The power equality of the incident wave is checked by means of the directional coupling fitted with a detector and a microammeter.

The detecting properties of the noise diode are used to measure the voltage between its anode and cathode. The voltage is measured by means of a compensation method [3,4].

The schematic of the equipment for calibrating diode noise generators is shown in Fig.3. The output of signal generator 1 is fed through a directional coupler with load 5 in its reflected wave arm and switch 6 first to power meter 8 which measures power P of the incident wave. At the same time a note is made of the reading of a microammeter 2 which is connected to detector 3 and whose readings are proportional to the incident wave. The signal is then fed to the diode noise generator 7 under test. If the microammeter 2 reading has changed the power of generator 1 is readjusted to restore the reading. The voltage across the diode is then measured by the compensation voltage meter 3. The value of Z_x is calculated from (10) where $[U_1]^2$ is the square of the effective voltage across the diode.

Measurement of the voltage across the diode. The high frequency voltage between the diode electrodes is measured by a compensating method [3], which consists essentially of the following. A certain current (of the order of a few microamperes) is set in the diode with the high frequency voltage disconnected. The high frequency voltage U_m is then connected and the diode current increases. A negative compensating voltage U_k is connected to the diode circuit in order to restore its current to the original value.

The voltampere characteristic of the diode is represented expontentially by $i = i_{oe}^{kU}$.

In [3] a table is given for obtaining from known values of $\underline{k}$ and U_k the correction ΔU_k which must be added to U_k in order to obtain the measured voltage amplitude U_m. The diode parameter $\underline{k}$ is found from two points on the volt-ampere characteristic

$$\kappa = \frac{\ln \frac{i_1}{i_2}}{U_2 - U_1}. \tag{11}$$

The voltampere characteristic of the noise diode 2D2S is exponential at currents below 5 μa.

The circuit used for measuring the high-frequency voltage across the diode electrodes is shown in Fig.4.

The initial diode current is set by means of resistor R_4 and the diode heater current. The heater voltage is set in the range of 1.1-1.5 v so as to make the diode current equal to 2.5-3 μa. The current is measured with a microammeter. A precision evaluation of the current is made by measuring the voltage drop across resistor R_7 by means of potentiometer PPTV-1. The compensation voltage in the diode circuit is controlled by resistor R_6 (rough) and potentiometer R_5 (precise). In the nonoperating position battery B_1 is disconnected by means of tumbler switch S_2. The compensation voltage is measured by means of potentiometer PPTV-1 across a potential divider consisting of resistors R_8 and R_9.

The measurements are made in the following order:

a) With the high-frequency voltage disconnected and switch S3 in position 1-2 the voltage drop across R_7 due to the diode current is measured by means of potentiometer PPTV-1.

b) The high-frequency voltage is connected across the diode (the power is of the order of 0.1-0.3 w). The compensating voltage is set by resistors R_5 and R_6 in order to bring the galvanometer G reading to zero without touching its controls. Thus, the diode current is returned to its original value.

c) Switch S3 is thrown to position 2-3 and the compensating voltage is measured on potentiometer PPTV-1 taking into consideration the potential divider R_8-R_9. The value thus obtained is equal to U_k. Its effective value is equal to $U_{k\,eff} = U_k/\sqrt{2}$. The effective value of the measured voltage is

$$U_1 = U_{\kappa\,eff} + \Delta U, \tag{12}$$

where ΔU is the correction obtained from the table given in [3].

The diode parameter k is determined, as has already been indicated, from two points on the voltampere characteristic. For this purpose resistor R_4 is shorted. The diode corrent is then set by means of the compensating voltage to read $i_1 \approx 2.5\text{-}3$ μa and the compensating voltage U_{k1} is measured. The latter is then changed by about 0.1 v. Thus, the second point of the characteristic (i_2, U_{k2}) is obtained, and the diode parameter is calculated from (11).

Errors of the method. There are three basic sources of error when noise generators are calibrated by this method: error in measuring power P of the incident wave at the noise generator input; error in measuring voltage U_1 across the diode; error due to the fact that the square of the noise current spectral density which is assumed according to (1) to equal $2eI_=$ is in fact slightly different from this value.

The error in measuring the incident wave power consists of the error of the power meter and the error in reproducing the incident wave power in switching the standard signal generator from the power meter to the noise generator.

For an infinite directivity of the coupler used for checking the incident wave power the latter error is extremely small (even if the detector does not operate in a square law condition) and is only due to the errors in reading the detector current on the microammeter.

If the directivity is limited the corresponding error does not exceed the value

$$\Delta = \frac{2}{N}(|\Gamma_p| + |\Gamma_g|), \tag{13}$$

where N is the voltage directivity in relative units; Γ_p is the reflection factor of the power meter; Γ_g is the reflection factor of the noise generator.

The deviation of the square of the noise current spectral density from $2eI_=$ can be due to two causes. Firstly to the limitation of the diode current by the space charge. In order to avoid this a sufficiently high voltage must be supplied to the diode anode. The current limitation can easily be detected by checking the linearity of the relation between the diode current and the noise power (by means of a superheterodyne receiver with a square law detector at its output). Experience has shown that this relationship for normal diodes 2D2S is linear with currents of 20-25 ma. Secondly, a reduction in the noise spectral density as compared with $2eI_=$ is due to the effect of the finite electron transit time at high frequencies. The error due to this effect is also small. Thus, according to the data in [2] the square of the noise current of a 2D2S diode is lowered by 6% at a wavelength of 20 cm. This result has been obtained by calculation. Experimental data given in [5] for a diode whose anode and cathode dimensions approach those of a 2D2S diode (the diode in [5] operates at a higher voltage, however) show that at a wavelength of 3.2 cm the power is only reduced by 20%. It is also possible to apply a correction for the electron transit time.

In calibrating the noise generator we used a power meter with a certified error of 10% and an input voltage standing wave ratio of 1.2; the noise generator input VSWR was also 1.2, and the directivity of the coupler exceeded 30 db.

Under these conditions the error due to the first two causes should not exceed 13.5-14% (i.e., 0.5-0.6 db). If more accurate power meters are used the total error can be reduced.

The error in measuring voltage across the diode at frequencies of 300–400 Mc does not exceed 1-2% according to the data given in [3]. At higher frequencies this error arises due to the finite electron transit time. Unfortunately, the lack of an experimentally checked theory of detection applicable to the types of diodes used and their operating condition made it impossible to evaluate theoretically this error. The basic criterion for evaluating the error consists in comparing the calibration results obtained by the above method with those obtained by means of a heated body radiation.

It should be noted that the above technique determines the power supplied by the noise generator to a load Z_0 which is matched to the transmission line, whereas noise generators are normally characterized by the power they supply to a load with a conjugate impedance. The error due to this fact does not exceed $[\Gamma_g]^2$, where $[\Gamma_g]$ is the modulus of the noise generator's reflection factor. Since in the majority of cases the voltage standing wave factor of diode noise generators does not exceed 1.2-1.3, these errors are smaller than 1-2%.

Comparison of the calibration results by means of the two methods. Impedances of three noise generators with 2D2S diodes were measured by this method. In these measurements a coupler with a directivity exceeding 30 db in the required range was used.

The input of the noise generator was supplied with a power of 80-300 mw; the high-frequency voltage across the diode then amounted to 2-6 v. The diode 2D2S parameter amounted to 5-6.

The above generators were also calibrated against a thermal source of noise on a reference equipment of the VNIIFTRI (All-Union Scientific Research Institute of Physicotechnical and Radiotechnical Measurements), which provided an error not exceeding 0.25 db. Calibrations were made at 6 points over the whole range of the standard signal generator GSS-15. A comparison of the calibration results showed that their discrepancy did not exceed 12.5%, i.e., 0.5 db.

In conclusion the authors wish to express their gratitude to L. A. Birger for his kind assistance in the check calibration of the diode noise generators.

LITERATURE CITED

1. A. Van-der-Zil, Fluctuations in Radiotechnology and Physics [Russian translation] (Gosénergoizdat, Moscow, Leningrad, 1958).
2. A. D. Kuz'min, Measurements of the Noise Factor in Receiving and Amplifying Devices [in Russian] (Gosénergoizdat, Moscow, Leningrad, 1955).
3. B. E. Rabinovich and A. M. Fedorov, Izmeritel'naya tekhnika, 1958, No. 2.
4. B. E. Rabinovich, Analysis of the Main Systematic Errors in the Method of Measuring Alternating Voltage by Compensating the Detected Current [in Russian] (Works of the VNIIM, No. 13/73, 1953).
5. S. I. Averkov, V. I. Anikin, and others. Radiotekhnika i élektronika, 1958, Vol. 1, No. 6.

All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

LIQUID AND GAS FLOW MEASUREMENTS

CONSTRUCTION OF CAPACITIVE LEVEL GAUGES

K. B. Karandeev, F. B. Grinevich, and A. I. Novik

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pp. 52-55, October, 1961

The essental advantage of capacitive gauges for measuring liquids and loose materials consists of the absence in their transducers of mobile elements and kinematic couplings with the external part of the instrument, and of their mechanical strength and reliability.

The operation of these gauges is based on measuring the capacity of the transducer which consists of a capacitor with insulated electrodes which are partially submerged in the measured medium (in many instances the container serves as one of the electrodes). The capacitance of such a capacitor depends not only on the extent to which the electrodes are submerged (the level of the medium), but also on the permittivity of the medium which is placed between the electrodes (the insulation of the transducer, the medium under test). Since the permittivity of the medium can change with time for various reasons (temperature variations, changes in the composition of the medium), considerable errors may arise in the level measurements. Thus, in designing capacitive level-gauges it is necessary to provide special means for compensating this error. In certain instances the medium can introduce considerable energy losses which may lead to additional errors.

The capacity of the level-gauge transducers is small and, as a rule, does not exceed a few hundred micromicrofarads. In the majority of cases it is impossible to place the measuring instrument in the immediate proximity of the transducer, making it necessary to use connecting cables, which may also reduce the accuracy of measurements.

The compensation method described in [1] is based on the most simple principle of operation, but involves complex apparatus for its application. It consists of measuring the permittivity of the medium by a special device, and correcting the level-gauge readings by means of auxiliary circuits. The level-gauge consists of two bridges with two capacitive transducers. The output signals of the bridges are compared by means of an autocompensated circuit which consists of an amplifier, a servomotor with a register, and a device which controls during measurements the supply voltage of one of the bridges. The level-gauge error is compensated in measuring permittivity over wide ranges.

A common defect of level-gauges with divided measurements of the tested media permittivity consists in their complexity. In simpler versions of this circuit only partial compensation of the error is possible. When two measuring circuits are used, considerable difficulties arise in protecting the device from stray electromagnetic couplings. Such level-gauges are unsuitable for measuring the boundary between two media, since the errors due to variations in the electrical parameters of the upper medium are not compensated.

A basically different method of designing level-gauges has been suggested in [2] and described in [3]. In this case a specially designed transducer is used for measuring the level as the ratio of two admittances (in a particular case—capacitances). The effect of the variation in electrical parameters of the medium is completely eliminated. The level-gauge measuring circuit then becomes simple and reliable. Such level-gauges can be used successfully for measuring levels in relatively low tanks (up to 0.5-1 m). The use of such instruments for measuring higher levels becomes difficult owing to the design peculiarities of their transducers. The latter circumstances as well as the difficulty in manufacturing and installing the transducers prevent the designing of a universal level gauge according to the method suggested in [2,3].

It has been noted above that capacitive level-gauges are affected to a considerable extent by the capacitance of connecting cables and its variation. In bridge-type level-gauges this effect can be reduced by using asymmetrical circuits in which the capacitance of the cable with suitable screening is connected in parallel with a large reference capacitance. However, this method cannot be considered satisfactory, since the sensitivity of the bridge circuit is then reduced to hundredths of its former value, which in many instances is not acceptable. Moreover, it is not always possible to obtain a satisfactory reduction in the error.

In [4] an original method of eliminating the effect of the connecting-cable capacity on the measurement results is suggested. The cable is made of a definite length and connected to a capacitive level-gauge, an induction coil and a resistance. Small variations of the cable capacitance in this case do not lead to measurement errors, provided the parameters of the circuit and the operating frequency are suitably selected. The defect of this circuit consists in the compensation of the cable capacitance effect on the measurement error being only applicable to cables of a given length with small variations in their electrical parameters.

Other types of level-gauge circuits described in literature either have no compensation whatsoever for the above mentioned errors, or employ extremely inefficient compensation methods.

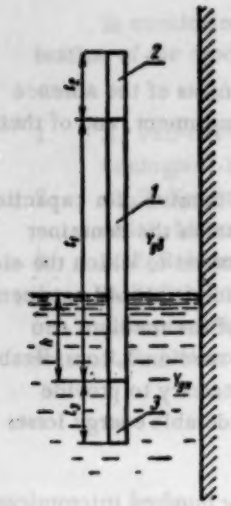


Fig. 1

In view of the above facts and the promising future of capacitive level-gauges it would appear desirable to continue the research on eliminating errors due to the instability of the media electrical parameters and the presence of stray capacitive couplings.

The Institute of Automation and Electrical Measurements of the Special Department of the Academy of Sciences, USSR, in conjunction with the Institute of Automation of the Academy of Sciences of the Kirghiz SSR have started work on finding new methods and designing circuits of level-gauges with compensation of the aforementioned errors as well as on designing discrete and digital level-gauges. Below we describe the circuit of one of the self-compensated capacitive level-gauges. The reading of the instrument, owing to the principle of its operation, does not depend on the electrical parameters of the medium between the electrodes of the transducer. The effect of the connecting cable on the readings of the instrument has also been virtually eliminated: its variation from zero to 500-700 $\mu\mu$f does not produce a noticeable error.

Let us assume that the transducer of the capacitive level-gauge consists of a cylindrical conductor with three sections 1,2, and 3 (Fig.1) of lengths l_1, l_2, and l_3 respectively which are insulated from each other and from the external medium. The transducer is placed vertically and parallel to the walls of the conducting cylindrical tank. The lower part of the transducer is immersed in the medium whose level $\underline{h}$ is to be measured.

If all the transducer sections have the same voltage difference with respect to the tank, it is possible to consider, by neglecting the end effects, that the admittance between each section of the transducer and the tank will be proportional to the length l of the section, i.e.

$$Y = Y_y \cdot l, \tag{1}$$

where Y_y is the specific admittance (admittance per unit length of the transducer) which depends on the dimensions and relative position of the transducer and the tank, the electrical parameters of the medium and the transducer insulation. For separate sections of the transducer we shall obtain according to (1):

$$\begin{aligned} Y_{1u} &= Y_{yu}(l_1 - h); \\ Y_{1l} &= Y_{yl}\, h; \\ Y_2 &= Y_{yu}\, l_2; \\ Y_3 &= Y_{yl}\, l_3. \end{aligned} \tag{2}$$

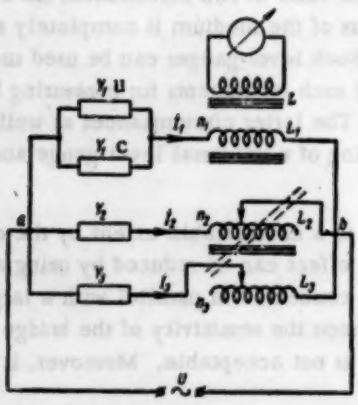


Fig. 2

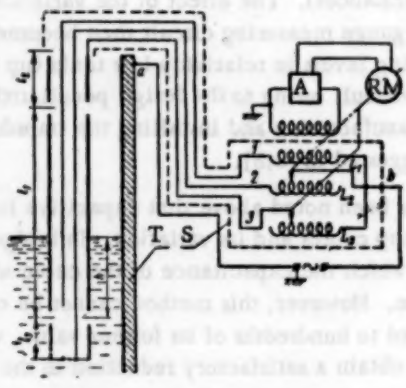


Fig. 3

Let us assume that the elements with admittances determined in (2) are included in the circuit represented in Fig.2. The circuit is supplied from a sinusoidal current source. Elements Y_1, Y_2, and Y_3 are connected in series with windings L_1, L_2, and L_3 which are wound on a single ferromagnetic core. Winding L is connected to a null-indicator. All the windings are closely coupled inductively to each other. The magnetic fluxes established by currents $\dot{I}_2$ and $\dot{I}_3$ in windings L_2 and L_3 are subtracted from the flux in winding L_1 due to current $\dot{I}_1$. The number of turns in windings L_1, L_2, and L_3 are respectively equal to n_1, n_2, and n_3.

This circuit constitutes a bridge with close inductive coupling and differs from the well-known circuits in [5,6] by having six instead of four arms. It can easily be seen that this bridge circuit will be balanced when

$$\dot{I}_1 n_1 - \dot{I}_2 n_2 - \dot{I}_3 n_3 = 0, \tag{3}$$

Moreover, the flux in windings L_1, L_2, and L_3 and their equivalent reactances will be equal to zero. Since it is possible to make the windings with ohmic resistances negligibly small compared with the resistances of the corresponding sections of the transducer, it is possible to write:

$$\dot{I}_1 = \dot{U}(Y_{1U} + Y_{1C}); \quad \dot{I}_2 = \dot{U}Y_2; \quad \dot{I}_3 = \dot{U}Y_3. \tag{4}$$

By inserting (2) and (4) into (3) we obtain:

$$(hn_1 - l_2 n_2)\, Y_{yl} + (l_1 n_1 - hn_1 - l_2 n_2)\, Y_{yu} = 0. \tag{5}$$

If the level $\underline{h}$ is determined directly from (5), variations in Y_{yu} and Y_{yl} will produce measurement errors. However, it is possible to determine level $\underline{h}$ independently of the values of Y_{yu} and Y_{yl} if the bridge (Fig.2) is balanced in such a manner that the coefficients of Y_{yu} and Y_{yl} become at balance equal to zero. Equation (5) will then be split up into the following two equations

$$hn_1 - l_2 n_2 = 0. \tag{6a}$$

$$l_1 n_1 - hn_1 - l_2 n_2 = 0. \tag{6b}$$

Level $\underline{h}$ is obtained from (6a) and is determined by the number of turns n_2 which must be adjustable. In order to obtain (6b) the number of turns n_2 must be adjusted. Thus, the bridge has to be balanced by adjusting the values of n_2 and n_3.

Let us determine from (6) the relationship which must be met in order to make the bridge workable.

By eliminating $\underline{h}$ from (6b) and assuming for simplicity that $l_2 = l_3 = l$ we have

$$n_2 + n_3 = n_1 \frac{l_1}{l}. \tag{7}$$

It follows from (7) that in balancing the bridge it is necessary to adjust the number of turns n_2 and n_3 in such a manner that their sum remains constant. Fig.2 shows one possible method for such an adjustment. The principle of operation of the above level-gauge provides a maximum measurable level of $h_{max} = l_1$. From (6) and (7) we obtain the following relationship for the maximum number of turns $n_{2\,max}$ and $n_{3\,max}$ determined for $h = h_{min} = 0$ and for $h = h_{max} = l_1$ respectively

$$n_{2\,max} = n_{3\,max} = n_1 \frac{l_1}{l}; \quad n_2 + n_3 = n_{2\,max} = n_{3\,max}. \tag{8}$$

It will be seen from (8) that the minimum number of turns for both windings L_2 and L_3 is equal to zero, i.e., the windings are equal.

The readings of level-gauges made according to the above circuit in theory will be independent of either the electrical parameters of the media whose boundary level is being measured or the dimensions and relative position of the transducer and the tank, or the parameters of the transducer insulation. Since the errors are compensated in the transducer and the measuring circuit itself, such a level-gauge can be called a self-compensating gauge.

The method of connecting the transducer to the measuring bridge is shown in Fig.3. In practice the transducer can be made of a three-conductor screened cable divided into three sections. The internal conductors 1,2, and 3 serve to connect the transducer sections to the measuring circuit. In order to eliminate undesirable electromagnetic couplings between the tank T and the measuring circuit components screen S is used. The bridge is balanced by a reversible motor RM operated by amplifier A.

In conclusion let us examine the effect of the cable capacitance and other undesirable capacitances on the measurement results. We shall limit ourselves to a purely qualitative analysis of the already mentioned circuit.

The undesirable capacitive effects on the level-measurement results can be reduced to the following three basic capacitances, namely, those between cable conducts 1,2, and 3; between screen S and the cable; and between screen S and tank T.

If we neglect the ohmic resistances of windings L_1, L_2, and L_3 we can assume, on the basis of (3), that currents $\dot{I}_1$, $\dot{I}_2$, and $\dot{I}_3$ do not produce voltage drops in L_1, L_2, and L_3. Hence, conductors 1,2, and 3 are at the same voltage point b. It is obvious that capacitive couplings between conductors 1,2, and 3 will not affect the measurement results under these conditions. Since screen S is connected to point b, and the cable as a whole is at point b potential, the capacitive coupling between the cable and the screen will not produce additional errors. The capacitive coupling between tank T and screen S provides a stray admittance between points a and b of the bridge, thus establishing an additional load across the supply source of the circuit which virtually has no effect on measurement results.

It follows from the above that the suggested level-gauge circuit has considerable advantages as compared with existing circuits. It provides by comparatively simple means a theoretically complete compensation of errors due to variations in the electrical parameters of the media between the transducer electrodes and affords a good protection from the effect of stray coupling capacitances. It is also important that the dimensions and relative positon of the transducer and the tank, the parameters of the transducer insulation and other factors which determine the transducer's unit length conductance Y_y do not affect the level-measurement results.

LITERATURE CITED

1. Gordon Victor Greatorex, Improvements in Circuits for obtaining Indications Dependent on Capacitance. British patent 37, 40(1), No. 826969 dated January 27, 1960.
2. K. B. Karandeev and L. N. Shteingauz, Authors's Certificate No. 45517 dated November 14, 1934.
3. K. B. Karandeev and L. N. Shteingauz, Electrical Method for Measuring Liquid Levels [in Russian] (Scientific Notes of the L'vov Polytechnical Institute, No. 5, Electrotechnical Series, No. 2, 1949).
4. Ya. M. Selektor, M. S. Ainutdinov, and S. M. Zombkovskii, Pribory i tekhnika éksperimenta, 1960, No. 3.
5. H. A. Clark and P. B. Vanderlyn, Double-ratio a. c. bridges with inductively coupled ratio arms, Proc. IEE, Vol. 96, p. III, 1949.
6. C. W. Oatley and J. G. Yates, Bridges with coupled inductive ratio arms as precision instruments for the comparison of laboratory standards of resistance or capacitance, Proc. IEE, 1954, Vol. 101, p. III.

All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

MATERIAL RECEIVED BY THE EDITORIAL BOARD

IMPROVING THE EXCHANGE OF EXPERIENCE BETWEEN THE GKL's (STATE INSPECTION LABORATORIES)

I. I. Kogan

Translated from Izmeritel'naya Tekhnika, No. 10,
p. 56, Ocotber, 1961

Since 1960 the Administration of the Representative of the Committee of Standards, Measures, and Measuring Instruments attached to the RSFSR Council of Ministers has striven to involve in checking the activity of the GKL s, the heads of these laboratories in addition to the engineers of the administration. Such inspections have been carried out in the Kalinin, Stavropol', Vladimir, Kemerovo, Rostov, and Tatar GKL s with the participation of the heads of the Smolensk, Checheno-Ingush, Kursk, Omsk, Voronezh, Ul'yanovsk, Chelyabinsk, and Saratov GKL s.

In the course of the inspections the heads of the GKL s exchange experiences, adopt from each other improved methods of working, and help to eliminate observed deficiencies. After the inspections production and technical conferences of the laboratory and district departments' personnel were held at which the inspection results were summarized and proposals for improving the activity of the GKL s were made.

Beneficial results of such inspection also consisted in the fact that when the heads of the GKL s returned to their districts they organized local inspections of the activity of their laboratories and applied the experience of other laboratories, thus eliminating various defects. For instance, the head of the Kursk GKL on his return from the Vladimir GKL used the latter's experience in checking the activity of instrument-making plants, of their service inspection agencies, in testing reference instruments at plants, and in organizing the activity of production rationalizers.

The head of the Smolensk GKL used the experience of the Kalinin GKL in issuing special instructions for the work of temporary branches. The activity of the laboratories is now being planned and organized in a new manner, with special attention being paid to individual planning of the work. At the same time the Kalinin GKL has adopted the Smolensk laboratory's experience in organizing the work of temporary branches, of organizing technical councils attached to the head of the GKL, and of checking the work of repair crews. The Vladimir GKL used the experience of the Kursk GKL in checking the work of repair crews and organizing temporary branches. The results of local inspections were discussed at production and technical conferences in the Smolensk and Kursk laboratories and measures were adopted for the elimination of the defects thus discovered.

When the checking of the GKL's activities was completed the Administration of the Representative of the Committee of Standards, Measures, and Measuring Instruments attached to the RSFSR Council of Ministers received the reports of the heads of the Kalinin and Vladimir laboratories, as well as the reports of the people who checked their activity.

The head of the Vladimir GKL presented his report to a group conference attended by 15 heads of laboratories. The head of the Kursk GKL in his parallel report informed the conference on the experience gained in local inspections by his laboratory. The parallel reports of the engineer from the Administration and the head of the Kursk GKL provoked a lively discussion aimed at improving the work of the GKL and critical of the Administration of the Committee of Standards, Measures, and Measuring Instruments. Among other things it was suggested that a definite technique in planning, testing, and inspection work of the GKL's should be introduced, and that forms for the primary data comprising the GKL reports should be established for use in compiling the plans of their work. In view of the enlargement of rural districts it was suggested that the technique and manner of organizing the work of the GKL temporary branches in the districts of the region should be specified. Considerable attention was also paid at the conference to the training of state inspectors, since at present, in view of the lack of state registered inspectors, state stamps are issued to persons without sufficient metrological training, which results in infringements of the Committee's testing instructions. Heads of the GKL s drew the conference's attention to the lack of miniature reference instruments in the GKL s for equipping mobile test laboratories. This fact is reflected in the lower quality of servicing the testing instruments in organizations and plants located at large distances from the GKL s.

The conference approved the drawing into participation in inspections organized the the Administration of the Committee's Representative of the heads of laboratories, and recommended that the heads of laboratories should continue their local inspections of laboratories.

The head of the Committee's State Inspection Department com. G. N. Sharonov reported to the conference on the experience gained in introducing new measuring equipment in other republics.

The Administration of the Committee's Representative summarized the work of the conference as well as the proposals by the heads of the GKL s, drew from it the necessary conclusions and submitted to the Committee several proposals aimed at improving the work of state inspection laboratories for measuring equipment.

UTILIZING CHECKING AND HEAVY INSPECTIONS FOR INSTRUCTIONAL PURPOSES

N. M. Ershov

Translated from Izmeritel'naya Tekhnika, No. 10,
p. 57, October, 1961

The owners of measures and measuring instruments often, due to their technical ignorance, use their equipment incorrectly. The checking and heavy inspection of instruments carried out at the plants by the local agencies of the Committee of Standards, Measures and Measuring Instruments should be used for training these owners. Temporary branches can be used with special effect in this connection, since they bring together a maximum number of workers in a given industry for general training.

For instance, in training workers of commercial establishments it is necessary to pay particular attention to the condition, accuracy, correct installation, and use of scales, to their maintenance and the clearing of minor defects by the workers of these establishments. A necessary minimum of practical advice should be given on how to clear these defects. The following example could be cited. Commercial workers often complain of the corrosion of weights. This defect can easily be cleared. It is only necessary to remove the graphite from 2-3 ordinary pencils, grind it and add to it a few drops of machine oil. The weights should be rubbed with this paste and then wiped clean. The weights will then acquire a finished appearance and their accuracy will remain within the tolerances.

In training dairy farm workers it is necessary to teach the milkmaids how to used milk measures (zero setting, filling, maintenance, etc.).

Information leaflets and other popular literature should be used in this training in order to supply the information on modern measuring equipment, and eventually bring it into use. In the Stanislav region such measures improved the condition of the measuring equipment.

GREATER ATTENTION SHOULD BE PAID TO RATIONALIZING TESTING

D. M. Sizov

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 57-58, October, 1961

The Zaporozh'e State Inspection Laboratory for Measuring Equipment pays particular attention to rationalizing testing. The GKL (State Inspection Laboratory) has established a BRIZ (Rationalization Bureau for Measuring Equipment) headed by its chief engineer. Periodically the BRIZ presents problems requiring rationalization to all the workers of the GKL. The rationalization proposals are examined in due time in the presence of their authors. The proposals accepted by the BRIZ are then referred to the Republican Administration.

In 1960 the BRIZ of our GKL received 28 rationalization proposals, of which 23 were accepted. A considerable part of these proposals have been adopted by GKL, which will reduce the time spent on state testing of instruments and raise the production norms in testing.

Of the rationalization proposals put into practice we should like to mention the following: tables and a slide rule of calculated errors for checking single- and three-phase electricity meters (V. A. Kotomin); an accelerated method of calculating the errors in the ratios of the UMV, MVU-49, MO-56, and MKMV bridges when their separate units are being checked, by means of this method the calculation time has been reduced by 40-50% (A. P. Lyubskaya); a table for computing corrections for the local accelerations due to gravitation, required in testing special weights of piston manometers (A. D. Podolyak); a table of measuring errors for potentiometers type KA-1 with a top measuring limit of 0.29 v, which reduces the time required for calculating test results by 25-30% (K. B. Portnova); a readout device used in checking analytical and reference (grade I and II) scales, as well as for checking analytical and reference weights, this device facilitates reading and raises the accuracy of testing (L. D. Verner); a table for testing commercial micromanometers with a variable tilt angle speeds up reading by 40-45% (V. Ya. Prokhorov); a device for checking stop-watches and a stand for stamping instruments.

More convenient certificate forms have been compiled, in particular for testing reference thermocouples. Moreover, various handy schematics for the testing of instruments have been produced, which facilitate the assimilation of new types of instruments by the young specialists or the new personnel of the GKL s.

However, by no means all the rationalization proposals have been adopted by the GKL and the Zaporozh'e region plants. Their assimilation is often held up owing to the lack of the required materials or the difficulty in making some of the devices, and sometimes simply due to underestimation of their importance. For instance, neither the GKL nor any of the plants of the region have adopted a device for fixing reference gauges in horizontal optimeters and measuring machines (D. A. Kaplan). The application of this device speeds up testing by 20-30%.

The rationalization work was carried out on the basis of a wide socialist emulation between both the workers and agencies of the GKL. Owing to the monthly check-up on the fulfilment of guarantees and the timely assistance given to individual workers it has been possible to fulfil all the engagements entered into, including those with respect to rationalization.

In conclusion we should like to note that the putting into effect of rationalization proposals is held up owing to their lengthy examination by the republican administration of the Committee of Standards, Measures, and Measuring Instruments. There have been instances when superior agencies rejected rationalization proposals alleging that they do not meet the requirements of the Committee's instructions. These decisions are not always correct. If a rationalization proposal deserves attention and is economically beneficial, it should be applied and the question of changing the instructions should be raised with the Committee. Some of the rationalization proposals which have been rejected by superior agencies are being used by our GKL with beneficial effect.

A timely and careful examination of the rationalization proposals would undoubtedly have a beneficial effect an improve rationalization in our sphere.

SUPERVISION OF MEASUREMENT EQUIPMENT IN METALLURGICAL PRODUCTION

K. N. Kizhaev

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 58-59, October, 1961

Modern metallurgical plants possess a large stock of measuring instruments and gauges, which makes the choice of the most efficient and economical methods of their supervision most important in metallurgical production. Below we describe the experience acquired by the test laboratory of the Izhevsk metallurgical plant.

The plant produces smelted steel, has hot and cold rolling mills, forging and stamping production, cast iron smelting, a mixed production shop, a repair shop, loading and transporting department, a power shop and other services.

In all these shops and services and the repair shops attached to them various mechanics use universal measuring gauges. A large number of measuring gauges is used in the production of these shops. Thus, in the hot and cold rolling mills a large number of double snap gauges is used for measuring metal sheets; in the wire-drawing shop measuring instruments consist of micrometers, adjustable and set snap gauges; in the repair and mixed production shops standard and special calipers, templets, and jigs are used; in forging and stamping production profile templets are used.

In view of the specific conditions of metallurgical plants they do not possess toool rooms. These circumstances affect the structure of the plant's test and repair agencies. Lacking the possibility of making for its own use production with a sufficient degree of accuracy (with the exception of templets used in model and forge-press production) the management is compelled to obtain outside the plant all its gauges, which often entails great difficulties.

Thus, in organizing test laboratories at metallurgical plants it is necessary to tackle the question of repairing defective measuring instruments.

At the Izhevsk metallurgical plant the repair problem arose very acutely following the routine visit to the plant by workers of the local state inspection laboratory who condemned a large part of the universal measuring gauges. It was then decided to organize the repairs of measuring gauges directly at the plant's test laboratory.

At present the laboratory comprises the following groups: testing group, consisting of 4 inspectors of the 5-6th grades; repair and adjusting group of 4 instrument mechanics of the 5-6th grades; control and checking stations (KPP) consisting of 14 inspectors. The head of the laboratory is subordinated to the technical control division, and is responsible for the measures and measuring instruments of all types.

The testing and certifying of various gauges is concentrated in the laboratory, including all the universal measuring gauges used in the shops and obtained from outside, as well as of reference equipment and working test instruments belonging to the laboratory and the KPP. The laboratory also tests, if requested by the shops, the instruments, gauges, calipers and components which cannot be tested by the KPP or by the shops themselves. This includes umpire testing.

Moreover, the test laboratory supervises the methods of testing and the development and adoption of new, hitherto unused, measuring equipment, and takes part in establishing what measuring gauges are required in production and how they should be allocated among the shops.

All the checking work in the test laboratory is carried out in strict conformity with the plant testing scheme and graphs. It is laid down that universal measuring gauges should be checked once every three months, block gauges once every six months, ect.

Before checking, the gauges are first examined and if necessary repaired in the repair shop or the laboratory. Such a procedure makes it possible to return for further use without undue delay serviceable, completely repaired and tested gauges, without causing any difficulties to the shops, since the work is not done to order but allocated to general plant expenses. The gauges which cannot be repaired are rejected and remain in the laboratory, i.e., are considered to be scrapped but are subsequently used for spare parts in repairs.

The laboratory workshop is fitted with lathes and lapping equipment and appropriate apparatus required for repairs. The equipment of the testing group comprises the minimum of instruments and gauges required for production measurements of length, angles, flatness, and linearity; as well as surface finish. The control and checking stations are set up in the workshops. Side by side with them are located the stations for repairing measuring gauges tested by the KPP, as well as the gauge stores, thus providing efficient servicing and timely repairs and testing of gauges. The repair mechanics belong to the shop personnel and are subordinate to the foreman in charge of gauges.

In some KPP s the inspectors issue the gauges to the workers besides checking them. This procedure reduces the number of storekeepers required for issuing gauges without causing any deterioration in the quality of testing. The work of the KPP inspectors can be organized depending on the working conditions of the shop either on the single-shift or three-shift basis. Each KPP or test laboratory inspector is assigned instruments for which he is responsible, including their timely checking.

All the laboratory inspectors must pass through a minimum of technical instruction in order to raise their metrological knowledge. After the successful completion of the course they acquire an appropriate grade. Inspectors of the test group receive their certificate from the local GKL and have the right to test measures and measuring instruments for linear and angle measurements. In view of the general improvement in the supervision of its measuring equipment the plant has received the right to check its own measuring instruments. This has resulted in a considerable saving for the plant and raised the authority of the measuring equipment inspection agencies in the plant.

INFORMATION

PROBLEMS OF RADIO-MEASUREMENT TECHNOLOGY AT THE SESSION DEDICATED TO THE RADIO DAY

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 59-60, October, 1961

The All-Union scientific session dedicated to the Radio Day was held on June 19-23, 1961.

At the radiotechnical measurements section of the conference 22 papers were read and discussed.

The first session of the section dealt with frequency and time measurements.

In the paper persented by G. A. Elkin and G. G. Rakhimov entitled "Utilization of Molecular Generators in the Time and Frequency Service" it was shown that an ammonia emission line molecular generator can be used for controlling the frequency of crystal-quartz oscillators with an accuracy of $\pm 5 \cdot 10^{-10}$. The paper examined the conditions of an accurate production of frequency which corresponds to the center of the molecular generator emission line.

The paper read by V. I. Skachkov and E. M. Zemskov dealt with the use of a cesium reference frequency in the time and frequency service.

In his paper "Transmission of Reference Frequencies over Short-Wave Radio Stations" G. N. Palii described the transmission of reference frequencies of highly-stable crystal-quartz oscillators certified as reference frequency standards. A block schematic of reference frequency standards was appended, and measurement results of supplementary errors due to transmission conditions were supplied.

Stray angle modulation which arises in frequency multipliers was analyzed in P. Ya. Khaskin's paper entitled "Types of Phase Distortions in Frequency Multipliers." This problem is relevant for designing multistage phase-stable frequency multipliers for molecular frequency standards.

The results of their research work in designing miniature high-precision crystal-quartz clocks were described in the paper of A. F. Plonskii and B. I. Shishkov on "Minature Transistorized Crystal-Quartz Clocks."

Two papers dealt with the ageing of crystal-quartz resonators. A. G. Smagin showed that the reason for the ageing of crystal-quartz elements consists of surface structural and contact unreversible changes. Certain surface finishing methods considerably reduce the effect of these causes. O. Sh. Grois in his paper described a possible mechanism for crystal-quartz ageing based on the vacancy diffusion towards the crystal lattice.

One of the section sessions dealt with power measurements at ultrahigh frequencies.

In her paper on "A Set of Power-Flux Meters" R. I. Nechaeva described sets of power-flux density meters used for determining the intensity of radiation from various radio-technical devices under laboratory, workshop, and field conditions, in the range of 180-16700 Mc.

V. A. Yugov and L. K. Vorob'ev proposed in their paper entitled "Thermistor-Bolometer for Measuring UHF Power" the design of a thermistor-bolometer which consists of a combination of a metal-film bolometer with a thermistor. The use of mass-produced thermistors and stable film elements opens up possibilities for the rapid assimilation of thermistor-bolometers in measurement technology.

In her paper V. V. Slutskaya dealt with thin-film thermal convertors for measuring UHF power.

L. M. Zaks and V. M. Petrov reported a new method of temperature compensation for UHF thermistor power meters.

Various problems in measuring impedances, field strength, and dielectric constants were dealt with in the papers of V. D. Starikov and B. A. Vostryakov on "Method for Measuring Automatically the Basic Parameters of High-Frequency Channels," of V. S. Buzinov on "Reference Equipment for Checking Field-Strength Meters," of V. B. Kazanskii, L. D. Stepin, and V. K. Tkach on "Application of a New Type of Resonance Method for Measuring Dielectric Constants in the Study of High-Molecular Compounds."

L. A. Pereverzev's paper dealt with the checking of the radiointerference meter's pulse characteristics. A. N. Virskii reported on a speedy sequential analysis of spectra; V. L. Kraitser and A. N. Ryskin reported the use of a super-ortikon for studying rapidly changing spectra.

N. P. Mitrofanov provided in his paper on a "Thermoelectronic Detector" the circuit, the principle of operation and the basic theory of a thermoelectronic detector.

The work of the section on radio measurements, at which, owing to the lack of time, only a part of the available papers was read, and that of the 1st All-Union Scientific and Technical Conference on Radio Measurements which took place in April, 1961 have shown a considerably increased volume of research and scientific and technical development in this sphere of radiotechnology.

2nd INTERNATIONAL CONFERENCE OF THE IMEKO

V. O. Arutyunov and A. N. Gavrilov

Translated from Izmeritel'naya Tekhnika, No. 10,
pp. 60-61, October, 1961

The 2nd International Scientific and Technical Conference on Measurement Techniques and Instrument-Making was held from June 26 to July 1, 1961 in Budapest with the participation of 25 countries. The preparation and organization of the conference was carried out by the International Preparatory Committee, which included representatives of Britain, Belgium, Bulgaria, Hungary, the German Democratic Republic, Poland, Rumania, USSR, USA, France, Czechoslovakia, Denmark, Italy, the Chinese People's Republic, Sweden, and other countries. All the practical organizational work was carried out by the permanent secretariat of the IMEKO formed by the Hungarian Scientific and Technical Society of Measurement Technology and Automation.

Experts from 22 countries read 142 papers, including 10 from Britain, 21 from Hungary, 18 from the GDR, 4 from the Chinese People's Republic, 16 from Poland, 2 from UAR, 11 from USA, and 17 from USSR.

At the first plenary session of the conference 6 general papers were read, consisting of those by V. O. Arutyunov (USSR) on the basic tendencies and problems in the development of measurement technology; by S. Carlyle (Britain) on measurement technology as the basis of automation; by E. G. Shramkov (USSR) on the contents of the "Measuring Instruments and Measurements" section of the international electrotechnical dictionary; by I. Terien (France) on the new determination of the meter in wavelength unit and the work of the International Bureau of Weights and Measures; by M. Jacob (Belgium) on legal metrology; by R. Kolosh (Hungary) on higher education in metrology.

The subsequent work of the conference was divided into 11 sections, those of metrology and terminology; computation and design of instruments; technology and organization of production; general application of electronics in instrument-making and measurement techniques; problems related to measurement techniques and automation; instruments and methods for measuring geometrical, mechanical, thermotechnical, physicochemical, electrical and magnetic quantities; instruments and methods for radiotechnical and ionizing radiation measurements.

At the concluding plenary session final reports which summed up the work of the three groups of sections of the conference were presented by H. Kortum (GDR), Malmstrom (Sweden) and V. O. Arutyunov (USSR).

In the near future the permament secretariat of the IMEKO will issue in the form of a single volume entitled "Acta IMEKO" the full text of all the papers read at the conference. The papers will be accompanied by short translations into Russian, English, and German.

We shall now give the brief contents of some of the reports which, in our opinion, are of greatest interest.

I. Obolski (Poland) submitted a draft for his dictionary of metrological terms in Polish, Russian, French, English, and German. He used in his work official Russian publications and scientific literature.

A. Portalupi described the detailed standard of terms and definitions on measurement technology compiled in Italy.

A. Ambrozi (Hungary) reported the development of a special computer for testing statically the quality of radio components (capacitors, transistors, electron tubes, etc.), under conditions of their mass or conveyor-belt production.

S. Orzepowski (Poland) dealt in his paper with the measurement of the parameters of rotating machinery by means of transistorized radiotransmitting devices which rotate together with the primary transducers and are connected by radio with stationary receivers. The above method ensures high reliability and sufficient accuracy.

V. Shackel (Britain) read a paper on the psychological and physiological processes in the human organism when working in production and, in particular, with measuring instruments. He unifies these problems under a new term, "ergonomics" and thinks that their systematization and study will lead to new requirements for the projected types of measuring equipment.

K. Mano and G. Maeumoto (Japan) reported on the use of television for counting particles, for instance, ephitrocites. The image of the particle is projected directly onto a screen, thus making it possible to measure the mean diameter of particles.

A large group of papers including 4 from Soviet experts dealt with the automation of measuring and controlling processes. T. Kemeny (Hungary) described an automatic compensator without rubbing contacts.

A. Agoston (Hungary) dealt with the application of non-linear elements in automatic compensators, which is of considerable importance in designing modern compensators.

I. Oshkhima's (Japan) paper deals with a method for recording automatically the frequency characteristics of automatic control systems by means of a special monitoring analyzer which uses rectangular pulses.

Z. Trnka (Czechoslovakia) described original designs and circuits of electromechanical instruments for obtaining frequency and transfer characteristics of linear elements.

V. Kvarnström (Sweden) in his paper dealt with a comparative evaluation of various methods for investigating the dynamic characteristics of instruments.

A. Rashed (UAR) dwelt in his report on the mathematical treatment of results obtained in measuring surface roughness and demonstrated the need to measure in three instead of two coordinates.

E. Szombati's (Hungary) paper provided a comprehensive review of the methods for computing pneumatic measuring heads and suggested a new method which incorporates several important factors.

The paper by F. Vazz and G. Gerb (Rumania) described an electropneumatic instrument intended for checking standard dimensions of components and supplied with a device for controlling automatically the lathe on which the detail is being machined.

A. Woschni (GDR) dwelt on the correction of dynamic characteristics of transducers by means of additional electrical correcting circuits.

V. Sternlicht's (USA) paper dealt with methods for measuring the thickness of an oil film in bearings. Various methods were reviewed, temperature relationships indicated and practical recommendations supplied.

H. Laport (GDR) dealt in his paper with the reasons for the instability of the mass of a reference kilogram.

G. Ruffino (Italy) described a new interferometer-dilatometer with a device which simultaneously measures variations in length and temperature.

In his paper A. Haas (Hungary) suggests a scientifically sound technique for calibrating surface contact thermometers and thermocouples.

Valuable information on reference radiation sources was given in a paper by R. Peyturo, M. Roanne, and G. Urbin (France). The authors compared certain ribbon tubes and evaluated the error in determining the actual temperature.

In his report T. Perles (USA) reviewed methods for measuring heat transfer.

The paper of Girten and Laponce (Britain) on measuring the absorbing and reflecting characteristics of surfaces in cosmic rocket casing materials deserves special attention.

Papers in the section on methods and instruments for measuring physical-chemical quantities included polarography, pH-meters, chromatography, vaccum measurements, spectroscopy, colorimetry, and gas analysis. In this section we should like to draw particular attention to the paper by D. Stricker and K. Tarnai (Hungary) which contains the theory, design, and technical characteristics of a new compensating ionization vacuum gauge. The "Modion" instrument is produced in small batches in the range of 10^{-3} to 10^{-6} mm Hg.

G. Mattock and E. Williams (Britain) reported on a new type of glass for the electrodes of pH-meters.

A valuable paper was read by E. Romer (Poland) on a new thermomagnetic oxygen gas analyzer with a low inertia.

Concrete data on modern Zeiss multipliers and on their further improvement were supplied by P. Gerlich (GDR).

In the section on instruments and methods for measuring electrical and magnetic quantities 7 papers dealt with problems of accuracy, thus indicating the topical nature and importance of this problem in modernconditions.

I. Pawlat (Austria) described the development of an original dual current transformer with a transformation ratio error of 0.02% and an angular error of 0.5'. The problem of raising accuracy in checking instrument transformers was also dealt with in the papers of Cho Kuo-ts'uan and others (Chinese People's Republic). Two papers, by H. Meyer (Switzerland) and by A. Ya. Bezikovich, D. I. Zorin, and T. B. Rozhdestvenskaya (USSR) dealt with precision measurements of current, voltage, and power in the range of 50 cps to 20 kc.

The utilization of the Hall effect for measuring power including that of three-phase circuits was dealt with in the paper of Yu Tieh-fi (Chinese People's Republic). D. Muster's (USA) paper dealt with the technique of measuring phase shifts in a distorted waveform.

A. Baltadjiev (Bulgaria) described measurements of permittivity by a direct reading instrument.

The section on radiotechnical measurements dealt with problems of measuring and checking materials and semimanufactured articles in the production of radiotechnical electronic devices, with instruments and methods used in radio broadcasting and communications, as well as with apparatus used for testing various radiotechnical devices.

In his paper E. Fischer (GDR) described in detail an instrument for measuring conductivity of crystal rods made of germanium and silicon.

D. Almassy and M. Uzsoki (Hungary) described their newly developed method for evaluating the power of waveguides by measuring the difference of temperatures over a specially prepared section of a waveguide wall. The authors indicate the possibility of obtaining by means of this method more accurate results in measuring powers up to 15 w.

G. Brunner (GDR) characterized the technical problems involved in the scintillation method of spectroscopic analysis in the cases of strong and weak radiation intensity. In his paper Z. Galotto (Italy) dealt with the problem of producing and calibrating photoneutron standards. The paper describes the design and method of measuring the intensity of a neutron source made in the shape of a sphere whose cavity contains an ampoule with 251.18 mg of radium in the form of $RaBr_2$.

T. Tanasecu (Rumania) analyzed on an example of γ-radiation transducer used for measuring radiation levels the problem of the reliability of γ-radiators and efficient means of protection against radiation. I. Perette (France) described the use of alpha-radiators for measuring the thickness of paper and cited results obtained in comparing them with β-radiators.

The International Preparatory Committee, which met during the same time at Budapest, decided to hold the next, 3rd conference of the IMEKO in 1964.

CONFERENCE OF THE ISO AND IEEC ON ACOUSTICS AND ELECTRICAL ACOUSTICS

I. G. Rusakov

Translated from Izmeritel'naya Tekhnika, No. 10,
p. 62, October, 1961

Conferences of the technical committees of the International Standardization Organization on Acoustics, ISO/TC-43 and of the International Electrical Engineering Commission on Electrical Acoustics, IEEC/TC-29 were held in Helsinki on July 5 to 16, 1961. These conferences were attended by representatives of 18 and 17 countries, respectively.

The conference of the ISO/TC-43 was opened by the Finnish delegate Prof. Jauhiainen, the plenary sessions were chaired by Prof. Dadson (National Physical Laboratory, Great Britain).

The conference adopted a resolution on the establishment of an initial level of acoustical power, having approved the Secretariat's proposal to adopt a threshold of 10^{-12} w. This threshold has been approved in the USSR.

In addition to plenary sessions, meetings of various selections were also held.

Audiometric threshold of audibility. Recommendations on an international threshold of audibility over a telephone were discussed in detail, taking into consideration more precise data obtained from comparing reference telephones of various countries including the Soviet Union.

A preliminary discussion was held on the problem of the initial level of the threshold of audibility through the bone of the forehead or through the mastoid (bone conduction). Agreement was reached on certain components of the vibrator used for studying bone conduction, such as the contact area of ~2 cm^2, spring pressure ~750 g-wt, a flat tip with a rounded edge of a radius of 1 mm.

Architectural acoustics. Discussion was continued on the draft ISO recommendation on measuring sound absorption by acoustical materials in reverberation chambers. It was agreed that such chambers should have a volume exceeding 180 m^3 and projected chambers or those under construction should, if possible, exceed 200 m^3.

Industrial and domestic noise. The conference was engaged in discussing and reaching agreement on the draft recommendation for evaluating and normalizing industrial and domestic noise. Confirming the previously adopted definitions in normalizing noise with the object of protecting hearing, curve PS 85 at 500, 1000, and 200 cps was taken as the basis (the curve of the limiting spectrum or the curve of noise classification No. 85). It was agreed at the same time that the permissible noise levels should be standardized in each country independently.

The method of evaluating interrupted noise was specified.

A working party of the ISO/TC-43 will in future study noise at aerodromes and in planes as a whole and from the point of view of its effect on the health of the population. The previously prepared draft recommendation on the method of measuring noise produced by means of transportation was discussed mainly from the point of view of the conditions for testing automobiles. It was decided to consult the ISO technical committee on automobiles in working out this draft.

The technique of evaluating the noise of machines was discussed. It was suggested to measure the noise level near the machines, to compute the noise level at standard distances from the machines, and to measure the acoustical power only in case the above methods were not applicable. However, it was recognized that the basic index of machine noise consists in the acoustical power radiated by the machine. This power should be evaluated in all cases.

Terminology. The drafting of an acoustical dictionary was discussed. This dictionary should contain, like the electro-acoustical dictionary of the IEEC both technical terms and definitions. It was decided to prepare a Russian-English as well as an English-French dictionary of this kind.

The plenary sessions of the IEEC/TC-29 were held under the chairmanship of Prof. Fourrer (Swiss Radio) and Prof. Kostin (Technical Physics Laboratory, Holland). The proposal by Japan on international reference measuring microphones and sources of sound, and on standard methods for their calibration were examined. A little later than Japan the Soviet Committee of the ISO submitted a proposal on standardizing the method of calibrating microphones in a free sound field. Both proposals were referred to the IEEC/TC-29. The conference rejected the Japanese proposal for establishing at present another working party, but entrusted the Japanese National Committee with the collection of existing information on standard microphones and sources of sound and on their calibration.

The sectional sessions of the IEEC/TC-29 conference examined the following problems regarding electroacoustical specifications.

Noise meter. The effect of the observer who is normally present at noise meter measurements was discussed in detail. The results of special investigations of this effect, carried out in the USA, were reported by Dr. Young. Distortions introduced by the observer are noticeable not only at higher frequencies by also at frequencies below 1000 cps. These data will be taken into account when drafting specifications for precision noise meters which were discussed at the conference. The conference decided to begin drafting a specification of a noise meter for measuring non-stationary and short-duration noises.

Transducers for measuring shocks and vibrations. The conference prepared a draft specification for the choice of characteristics of vibration and shock transducers, and made a suggestion on the choice of auxiliary equipment characteristics for measuring shocks and vibrations. It was decided to draft a specification on the choice of characteristics for electrodynamic vibration generators and on the technique for calibrating vibration transducers.

Selection of an artificial ear, an artificial voice, etc. At the meeting of the section Dr. Bruel (Denmark) read a paper on comparing the characteristics of 5 types of artificial ear instruments. The instruments were made according to simplified designs of the existing types adopted in various countries (France, Denmark, Great Britain, USA, and Switzerland). It was decided to carry out a repeated, more careful investigation of these instruments in order to obtain characteristics of various audiometric telephones with different artificial ear instruments. Prof. Grützmacher (Federal Physical-Technical Institute, FRG) agreed to carry out these tests by November 1, 1961. Several countries, including the USSR, were asked to submit for these tests their audiometric telephones and to test the telephones by means of the instrument developed by Dr. Bruel.

Sound recording. Problems of sound recording were discussed separately by a sub-committee of the IEEC/SC-29 a, which was also held at Helsinki. Soviet proposals on specifying the frequency characteristic of magnetic recording, which is of great practical importance for improving the quality of recording and facilitating international exchange of radio and television programs, were approved by the conference.

FROM FOREIGN JOURNALS

Translated from Izmeritel'naya Tekhnika, No. 10, p. 63, October, 1961

BULLETIN DE L'ORGANISATION INTERNATIONALE DE METROLOGIE LEGALE (1)

1960, December, No. 2

R. Viewer. Importance of a national laboratory of legal metrology.

Z. Rauszer. Values and units of measurements (continuation).

Measuring instruments service in France. Draft law on measuring units and measuring instrument testing (continuation).

New determination of the meter.

A. Rust. Mobile test laboratories (continuation and conclusion).

Information. Documents.

1961, March, No. 3

M. Costamagna. International prospects for legal metrology.

Z. Rauszer. Values and units of measurements.

Weights and measures service in Sweden. The weights and measures law.

Measuring instruments service in France. Mechanization of the legal metrology services.

Information. Documents.

1961, June, No. 4

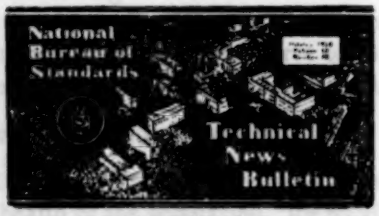
Documents on the history of metrology. Austria. Weights and Measures Law of August 23, 1777.

Weights and measures service in Hungary. Decree on legal metrology.

E. Plunian. Autotrucks for testing oil-product meters.

Information. Documents.

(2)



1961, No. 1

Conference on measuring problems. A number of conferences are being organized in the USA on special measurements required in the production of rockets and guided missiles.

Atomic frequency standards. A new caesium standard which controls a crystal-quartz generator used for supplying precision time signals.

1961, No. 2

Standard samples of materials. Samples are produced by the NBS for checking chemical processes, instruments and equipment.

Attestation of block gauges.

1961, No. 3

60th anniversary of the NBS foundation.

Calibration of platinum resistance thermometers used by the NBS.

1961, No. 4

Measurement of the resolution of precision lenses.

1961, No. 5

Testing inductance potential dividers. Methods and equipment used by the NBS.

Development of luminence standards and NBS methods of testing luminence.

New recording instrument for measuring viscosity and elasticity of rubber. Viscosity measuring limits from 10^6 to 10^{12} poise. Spring-back measurements over a period from 1 sec to 1 day.

A new NBS laboratory for measuring radiation down to 10^{-12} C.

Short review of the work carried out by the NBS.

(3)

1961, No. 288

J. Stolz. Flow measurements by means of diaphragms used in testing steam turbines.

G. Ney. Limits of reliability in recorder indications. Test data of commercial automatic potentiometers are provided.

Measurements of the weight of oil products by the bubbling method. A Debrot manoscope is described.

E. Rozner. Flowmeter with oval gears and its versions for various purposes.

P. Gondet. Measurement and recording of weak gas pressures. Measuring limits of ± (2—10) μbar, error of 1%.

No. 289

"Mesucora 1961" Exhibition (Paris, May, 1961).

New pneumatic micrometer. The new micrometer "Ermatic" which has a great magnification is described.

No. 290

The problem of controlling the voltage of supply sources.

(4)

1961, No. 300, January

H. Gummel. The principle of operation and application of gas analyzers. The main types of gas analyzers and methods of automatic analysis are described.

F. Klutke. Precision methods for measuring variations of capacitance and inductance in systems which exhibit locking phenomena.

W. Wichovski. Instruments for measuring luminence.

G. Engelgardt. Recording gas analyzers. Application of the "Termofinx" method.

W. Wust. Measurement of pressure differences in liquids and gases.

W. Philip. Precision methods for measuring electrical power.

No. 301, February

G. Schwarz. Methods and instruments for measuring small gas pressures. Description of various vacuum gauges with amplifiers.

R. Rulman. Measurements of the amplitude and duration of voltage pulse fronts.

W. Wisner. Precision capacitance measurements. Part 2. The effect of factors influencing the accuracy of measurements is analyzed.

O. Masek. Phase measurements at audio and higher frequencies.

G. Jung. Pneumatic auxiliary instruments for flow-meters. Description of a device for remote transmission of readings, of automatic batching, selection of liquid samples and flow measurements.

G. Trap. Successes in designing scales.

IN THE COMMITTEE OF STANDARDS, MEASURES AND MEASURING INSTRUMENTS

Translated from Izmeritel'naya Tekhnika, No. 10,
p. 63, October, 1961

I. New Specifications for Measures and Measuring Instruments Approved by the Committee

New Standards
(Registered in August, 1961)

GOST (All-Union State Standard) 2641-61. Synchronous micromotors for instruments. Replacing GOST 2641-44. Effective from January 1, 1962.

GOST 6923-61. Telescopes for radiation pyrometers. Replacing 6923-54. Effective from July 1, 1962.

GOST 9847-61. Optical instruments for determining surface roughness. Types. Basic parameters and accuracy standards. First application. Effective from July 1, 1963.

GOST 9377-60. Diamond tips for measuring hardness by the Rockwell and Vickers methods. The GOST comes into force on July 1, 1962 instead of July 1, 1961.

New Instructions for Testing Measures and Measuring Instruments

Instruction 103-61 for testing glass plates used in interference measurements. Replacing instruction 103-53. Effective from January 1, 1962.

Instruction 135-61 for testing micrometers. Replacing instruction 135-57. Effective from January 1, 1962.

Instruction 164-61 for testing pyrometer millivoltmeters. Replacing instruction 164-54. Effective from January 1, 1962.

II. Operating Instructions Issued for Testing Measures and Measuring Instruments and Approved by the Committee's Measuring Instruments Administration

Operating instructions No. 185 for testing thermal meters TS-1 and their test racks. Effective from January 1, 1962.

Operating instructions No. 186 for testing torsion microbalances MV-1. Effective from January 1, 1962.

III. Measures and Measuring Instruments Approved by the Committee as the Result of State Testing and Passed for Use in the USSR

(Registered in July-August, 1961)

Miniature pulse generator, trade mark MGI-1. State Register No. 1510-61.

Photocompensated comparator, trade mark F-13. Leningrad Sovnarkhoz (Council of national economy). State Register No. 1511-61.

Direct-current bridge (ordinary) Trade Mark MO-59 L'vov Sovnarkhoz. State Register No. 1512-61.

Micrometer hole gauge, trade mark NMI 1250-4000. Chelyabinsk Sovnarkhoz. State Register No. 1513-61.

Operating test rulers. Trade Mark KL. Moscow Regional Sovnarkhoz. State Register No. 1514-61.

Automatic balances for conveyor belts. Trade Mark LTM, Moscow Regional Sovnarkhoz. State Register No. 1515-61.

Automatic colorimeter for oil products. Trade mark AKN-57. Kiev Sovnarkhoz. State Register No. 1516-61.

Electrical tachometers. Trade Mark K 16. Leningrad Sovnarkhoz. State Register No. 1517-61.

Micro-voltamperweber meters. Trade Mark F-18. Leningrad Sovnarkhoz. State Register No. 1518-61.

Multirange ammeters. Trade Mark M1104. Leningrad Sovnarkhoz. State Register No. 1519-61.

Multirange portable millivoltmeters. Trade Mark M1105. Leningrad Sovnarkhoz. State Register No. 1520-61.

Multirange portable voltmeters. Trade Mark M1106. Leningrad Sovnarkhoz. State Register No. 1521-61.

Multirange portable voltmeters. Trade Mark M1107. Leningrad Sovnarkhoz. State Register No. 1522-61.
Multirange portable voltammeters. Trade Mark M1108. Leningrad Sovnarkhoz. State Register No. 1523-61.
Multirange portable millivoltammeters. Trade Mark M1109. Leningrad Sovnarkhoz. State Register No. 1524-61.
Shunts. Trade Mark 100ShS. Krasnodar Sovnarkhoz. State Register No. 1525-61.
Pulsed synchroscopes. Trade Mark S-1-5 (SI-1). State Register No. 1526-61.

Soviet Journals Available in Cover-to-Cover Translation

ABBREVIATION	RUSSIAN TITLE	TITLE OF TRANSLATION	PUBLISHER	TRANSLATION BEGAN Vol.	Issue	Year
AÉ	Atomnaya énergiya	Soviet Journal of Atomic Energy	Consultants Bureau	1	1	1956
Akust. zh.	Akusticheskii zhurnal	Soviet Physics – Acoustics	American Institute of Physics	1	1	1955
	Antibiotiki	Antibiotics	Consultants Bureau	4	1	1959
Astr(on). zh(urn).	Astronomicheskii zhurnal	Soviet Astronomy–AJ	American Institute of Physics	34	1	1957
Avto(mat). svarka	Avtomaticheskaya svarka	Automatic Welding	British Welding Research Association (London)		1	1959
	Avtomatika i Telemekhanika	Automation and Remote Control	Instrument Society of America	27	1	1956
	Biofizika	Biophysics	National Institutes of Health*		1	1957
	Biokhimiya	Biochemistry	Consultants Bureau	21	1	1956
Byull. éksp(erim). biol. i med.	Byulleten' éksperimental'noi biologii i meditsiny	Bulletin of Experimental Biology and Medicine	Consultants Bureau	41	1	1959
DAN (SSSR) / Dokl(ady) AN SSSR	Doklady Akademii Nauk SSSR	The translation of this journal is published in sections, as follows:				
		Doklady Biochemistry Section	American Institute of Biological Sciences	106	1	1956
Life Sciences		Doklady Biological Sciences Sections (includes: Anatomy, biophysics, cytology, ecology, embryology, endocrinology, evolutionary morphology, genetics, histology, hydrobiology microbiology, morphology, parasitology, physiology, zoology sections)	American Institute of Biological Sciences	112	1	1957
Life Sciences		Doklady Botanical Sciences Sections (includes: Botany, phytopathology, plant anatomy, plant ecology, plant embryology, plant physiology, plant morphology sections)	American Institute of Biological Sciences	112	1	1957
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology	Consultants Bureau	106	1	1956
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Chemistry	Consultants Bureau	106	1	1956
Chemical Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry	Consultants Bureau	112	1	1957
Earth Sciences		Doklady Earth Sciences Sections (includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections)	American Geological Institute	124	1	1959
				106-123	1	1957-1958
Earth Sciences		Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry	Consultants Bureau	106-123	1	1957-1958
Earth Sciences		Proceedings of the Academy of Sciences of the USSR, Sections: Geology	Consultants Bureau	131	1	1961
Mathematics		Doklady Soviet Mathematics	The American Mathematics Society			
Physics		Soviet Physics–Doklady (includes: Aerodynamics, astronomy, crystallography, cybernetics and control theory, electrical engineering, energetics, fluid mechanics, heat engineering, hydraulics, mathematical physics, mechanics, physics, technical physics, theory of elasticity sections)	American Institute of Physics	106	1	1956
Physics		Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections)	Consultants Bureau	106-117	1	1956-1957
Derevoobrabat. prom-st'.	Derevoobrabatyvayushchaya promyshlennost'	Wood Processing Industry	Timber Development Association (London)		9	1959
	Élecktrosvyaz	Telecommunications	Massachusetts Institute of Technology*		1	1957
Éntom(ol). oboz(renie)	Entomologicheskoe obozrenie	Entomological Review	American Institute of Biological Sciences	38	1	1959
Farmakol. (i) toksikol(ogiya)	Farmakologiya i toksikologiya	Pharmacology and Toxicology	Consultants Bureau	20	1	1957
FMM	Fizika metallov i metallovedenie	Physics of Metals and Metallography	Acta Metallurgica*	5	1	1957
Fiziol. zhurn. SSSR (im. Sechenova)	Fiziologicheskii zhurnal im. I. M. Sechenova	Sechenov Physiological Journal USSR	National Institutes of Health*		1	1957
Fiziol(ogiya) rast.	Fiziologiya rastenii	Plant Physiology	American Institute of Biological Sciences	4	1	1957
	Geokhimiya	Geochemistry	The Geochemical Society		1	1958
FTT	Fizika tverdogo tela	Soviet Physics–Solid State	American Institute of Physics	1	1	1959
Izmerit. tekh(nika)	Izmeritel'naya tekhnika	Measurement Techniques	Instrument Society of America		1	1959
Izv. AN SSSR, O(td). Kh(im). N(auk)	Izvestiya Akademii Nauk SSSR: Otdelenie khimicheskikh nauk	Bulletin of the Academy of Sciences of the USSR: Division of Chemical Sciences	Consultants Bureau		1	1952

continued

Izv. AN SSSR, O(td). T(ekhn). N(auk): Met(all). i top.	(see Met. i top.)	Bulletin of the Academy of Sciences of the USSR: Physical Series	Columbia Technical Translations	1	1954
Izv. AN SSSR Ser. fiz(ich).	Izvestiya Akademii Nauk SSSR: Seriya fizicheskaya	Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series	American Geophysical Union	1	1954
Izv. AN SSSR Ser. geofiz.	Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya	Izvestiya of the Academy of Sciences of the USSR: Geologic Series	American Geological Institute	1	1958
Izv. AN SSSR Ser. geol.	Izvestiya Akademii Nauk SSSR: Seriya geologicheskaya	Soviet Rubber Technology	Research Association of British Rubber Manufacturers	18 1	1 1959 3 1960
Kauch. i rez.	Kauchuk i rezina	Kinetics and Catalysis	Consultants Bureau		1 1958
	Kinetika i kataliz	Coke and Chemistry USSR	Coal Tar Research Association (Leeds, England)	14	1 1952
	Koks i khimiya	Colloid Journal	Consultants Bureau	2	1 1957
Kolloidn. zh(urn).	Kolloidnyi zhurnal	Soviet Physics – Crystallography	American Institute of Physics	6	1 1958
Metalov. i term. obrabot. metal.	Kristallografiya Metallovedenie i termicheskaya obrabotka metallov	Metal Science and Heat Treatment of Metals	Acta Metallurgica		1 1957
Met. i top.	Metallurg	Metallurgist	Acta Metallurgica		1 1960
Mikrobiol.	Metallurgiya i topliva	Russian Metallurgy and Fuels	Eagle Technical Publications		1 1957
OS	Mikrobiologiya	Microbiology	American Institute of Biological Sciences	26	6 1959
	Optika i spektroskopiya	Optics and Spectroscopy	American Institute of Physics		1 1958
	Pochvovedenie	Soviet Soil Science	American Institute of Biological Sciences		
	Priborostroenie	Instrument Construction	British Scientific Instrument Research Association		1 1959
Pribory i tekhn. éks(perimenta)	Pribory i tekhnika éksperimenta	Instruments and Experimental Techniques	Instrument Society of America		1 1957
Prikl. matem. i mekh.	Prikladnaya matematika i mekhanika	Applied Mathematics and Mechanics	American Society of Mechanical Engineers		1 1958
PTÉ	(see Pribory i tekhn. éks.)		National Research Council of Canada	12	1 1957
	Problemy Severa	Problems of the North	Massachusetts Institute of Technology*	2	1 1957
Radiotekh.	Radiotekhnika	Radio Engineering	Massachusetts Institute of Technology*		1 1959
Radiotekh. i élektronika	Radiotekhnika i élektronika	Radio Engineering and Electronics	Production Engineering Research Assoc.		1 1959
	Stanki i instrument	Machines and Tooling	Iron and Steel Institute	13	1 1956
	Stal'	Stal (In English)	Consultants Bureau		4 1959
Stek. i keram.	Steklo i keramika	Glass and Ceramics	British Welding Research Association		
Svaroch. proiz-vo	Svarochnoe proizvodstvo	Welding Production	Society for Industrial and Applied Mathematics		1 1956
Teor. veroyat. i prim.	Teoriya veroyatnostei i ee primenenie	Theory of Probability and Its Applications			1 1960
Tsvet. Metally	Tsvetnye metally	Nonferrous Metals	Primary Sources	66	1 1958
UFN	Uspekhi fizicheskikh Nauk	Soviet Physics – Uspekhi (partial translation)	American Institute of Physics		1 1960
UKh	Uspekhi khimii	Russian Chemical Reviews	The Chemical Society (London)	15	1 1960
UMN	Uspekhi matematicheskikh nauk	Russian Mathematical Surveys	London Mathematical Society		
Usp. fiz. nauk	(see UFN)				
Usp. khim(ii)	(see UKh)				
Usp. matem. nauk	(see UMN)				
Usp. sovr. biol.	Uspekhi sovremennoi biologii	Russian Review of Biology	Oliver and Boyd		48 1959
Vest. mashinostroeniya	Vestnik mashinostroeniya	Russian Engineering Journal	Production Engineering Research Assoc.		4 1959
Vop. gem. i per. krovi	Voprosy gematologii i perelivaniya krovi	Problems of Hematology and Blood Transfusion	National Institutes of Health*		1 1957
Vop. onk.	Voprosy onkologii	Problems of Oncology	National Institutes of Health*		1 1957
Vop. virusol.	Voprosy virusologii	Problems of Virology	National Institutes of Health*		1 1957
Zav(odsk). lab(oratoriya)	Zavodskaya laboratoriya	Industrial Laboratory	Instrument Society of America	25	1 1959
ZhAKh Zh. anal(it). khimii	Zhurnal analiticheskoi khimii	Journal of Analytical Chemistry USSR	Consultants Bureau	7	1 1952
ZhETF Zh. éksperim. i teor. fiz.	Zhurnal éksperimental'noi i theoreticheskoi fiziki	Soviet Physics–JETP	American Institute of Physics	28	1 1955
ZhFKh Zh. fiz. khimii	Zhurnal fizicheskoi khimii	Russian Journal of Physical Chemistry	The Chemical Society (London)		7 1959
ZhMÉI Zh(urn). mikrobiol. épidemiol. i immunobiol.	Zhurnal mikrobiologii, épidemiologii i immunobiologii	Journal of Microbiology, Epidemiology and Immunobiology	National Institutes of Health*		1 1957
ZhNKh Zh(urn). neorgan(ich). khim(ii)	Zhurnal neorganicheskoi khimii	The Russian Journal of Inorganic Chemistry	The Chemical Society (London)		1 1959
ZhOKh Zh(urn). obshch(ei) khimii	Zhurnal obshchei khimii	Journal of General Chemistry USSR	Consultants Bureau	19	1 1949
ZhPKh Zh(urn). prikl. khimii	Zhurnal prikladnoi khimii	Journal of Applied Chemistry USSR	Consultants Bureau	23	1 1950
ZhSKh Zh(urn). strukt. khimii	Zhurnal strukturnoi khimii	Journal of Structural Chemistry	Consultants Bureau	1	1 1960
ZhTF Zh(urn). tekhn. fiz.	Zhurnal teknicheskoi fiziki	Soviet Physics–Technical Physics	American Institute of Physics	26	1 1956
Zh(urn). vyssh. nervn. deyat. (im. Pavlova)	Zhurnal vysshei nervnoi deyatel'nosti (im. I. P. Pavlova)	Pavlov Journal of Higher Nervous Activity	National Institutes of Health*		1 1958

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SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

AN SSSR	*Academy of Sciences, USSR*
FIAN	*Physics Institute, Academy of Sciences USSR*
GITI	*State Scientific and Technical Press*
GITTL	*State Press for Technical and Theoretical Literature*
GOI	*State Optical Institute*
GONTI	*State United Scientific and Technical Press*
Gosénergoizdat	*State Power Press*
Gosfizkhimizdat	*State Physical Chemistry Press*
Goskhimizdat	*State Chemistry Press*
GOST	*All-Union State Standard*
Gostekhizdat	*State Technical Press*
GTTI	*State Technical and Theoretical Press*
IAT	*Institute of Automation and Remote Control*
IF KhI	*Institute of Physical Chemistry Research*
IFP	*Institute of Physical Problems*
IL	*Foreign Literature Press*
IPF	*Institute of Applied Physics*
IPM	*Institute of Applied Mathematics*
IREA	*Institute of Chemical Reagents*
ISN (Izd. Sov. Nauk)	*Soviet Science Press*
IYaP	*Institute of Nuclear Studies*
Izd	*Press (publishing house)*
LÉTI	*Leningrad Electrotechnical Institute*
LFTI	*Leningrad Institute of Physics and Technology*
LIM	*Leningrad Institute of Metals*
LITMiO	*Leningrad Institute of Precision Instruments and Optics*
Mashgiz	*State Scientific-Technical Press for Machine Construction Literature*
MGU	*Moscow State University*
Metallurgizdat	*Metallurgy Press*
MOPI	*Moscow Regional Pedagogical Institute*
NIAFIZ	*Scientific Research Association for Physics*
NIFI	*Scientific Research Institute of Physics*
NIIMM	*Scientific Research Institute of Mathematics and Mechanics*
NIKFI	*Scientific Institute of Motion Picture Photography*
NKTM	*People's Commissariat of the Heavy Machinery Industry*
Obrongiz	*State Press of the Defense Industry*
OIYaI	*Joint Institute of Nuclear Studies*
ONTI	*United Scientific and Technical Press*
OTI	*Division of Technical Information*
OTN	*Division of Technical Science*
RIAN	*Radium Institute, Academy of Sciences of the USSR*
SPB	*All-Union Special Planning Office*
Stroiizdat	*Construction Press*
URALFTI	*Ural Institute of Physics and Technology*
TsNIITMASh	*Central Scientific Research Institute of Technology and Machinery*
VNIIM	*All-Union Scientific Research Institute of Metrology*

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us — *Publisher.*

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